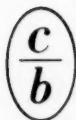


Volume 20 Number 10
October 1950

JOURNAL OF
GENERAL
CHEMISTRY
of the USSR

ЖУРНАЛ ОБЩЕЙ ХИМИИ
(ZHURNAL OBSHCHEI KHIMII)

TRANSLATED FROM RUSSIAN



CONSULTANTS BUREAU, NEW YORK

#10

THE JOURNAL OF GENERAL CHEMISTRY
OF THE USSR

Vol. 20, 1950

OCT.

IN ENGLISH TRANSLATION

CONSULTANTS BUREAU
152 West 42nd St., New York 18, N. Y.

—An agency for the interpretation of international knowledge—

TABLE OF CONTENTS

		page	Russ. page
1. The Colors of Metal Carbonyls and of Various other Substances.	D. A. Pospelkov	1797	1737
2. Aluminum Fluoride Complexes in Solution.	K. E. Kleiner	1807	1747
3. The Nature of Crystals. VI. The Interatomic Linkage of Organic Crystals and the Mutual Solubility of Organic Substances.	V. Ya. Kurbatov	1821	1760
4. Mutual Solubility in the System $H_2CO_3-K_2O_3-H_2O$.	Ya. Ugey and T. Siskina	1829	1768
5. The Relationship between the Amount of Cation Adsorbed and the Weight of Adsorbent.	A. T. Davidov and I. Ya. Levitsky	1837	1776
6. Certain Internal Complex Compounds of the Elements of Group II and their Solubilities.	K. V. Astakhov and E. D. Kiseleva	1841	1780
7. The Chemistry of the Processes of Decolorization of Dyes with Silver. III. The Reduction of Azo Dyes with Silver in a solution of Sodium Sulfide.	G. I. Arbutov and L. I. Gilman	1847	1786
8. The Preparation of Free Imidosulfamide and its Properties.	A. V. Kirsanov and Yu. M. Zolotov	1851	1790
9. Betaine-like Compounds Formed by the Splitting off of a Proton from the NH Group. V. Derivatives of μ -Anthraquinone Sulfonic Acid.	A. M. Simonov and N. P. Anshakova	1865	1802
10. Aminoalkyl Esters of Thiazocarboxylic Acids. II. 2-Phenylbenzothiazole-6-Carboxylic and 2-(p-Aminophenyl)-Benzothiazole-6-Carboxylic Acids.	S. G. Fridman	1871	1807
11. The Preparation of Acenaphthylene.	E. M. Mikhailov and A. N. Elchikina	1881	1816
12. Studies in Sulfonation. XIV. The Preparation of Sulfonyl Chlorides from the Sodium Salts of Sulfonic Acid.	A. A. Spriskov and N. V. Ananyeva	1883	1818
13. The Question of the Most Convenient Method of Preparation of β -Alanine.	A. N. Parshik	1891	1826
14. Derivatives of Acetylene. 118. The Condensation of Vinylacetylene with Dimethoxyketones. The Synthesis and Transformation of Vinylthiaryl Carbinols Containing Two Methoxyl Groups.	I. N. Nazarov and S. A. Vartanov	1895	1829
15. Derivatives of Acetylene. 119. The Mechanism of Hydration and Cyclization of the Diamines. XXVI. The Behavior of 5,6-Dimethyl-1,5-Heptadien-3-ine During Hydration and Cyclization.	I. N. Nazarov and S. B. Bakhtskaya	1903	1837
16. The Preparation of 3,5-Dichlorophthalic Acid.	A. A. Ponomarenko and T. E. Matsievich	1911	1845
17. The Synthesis of 2-Methylpyrrolidine.	P. S. Ustyuzhnikov	1913	1848
18. Quinonebromolimides and Quinonedibromodilimides.	S. I. Burmistrov and N. A. Zuykova	1917	1852
19. The Oxime of Acetoacetic Acid (β -Hydroxyiminobutyric Acid).	N. V. Khromov	1923	1858
20. Investigations in the Domain of Aliphatic Aromatic Acetylene Glycols. I. The preparation and Properties of Symm. Dimethyldi-p-tolyl-butylidol (Di-p-tolyl-2,5-hexin-3-diol-2,5).	A. I. Lebedeva and E. P. Riskina	1933	1869
21. The Sulfonation and Sulfonic Acids of Acidophobic Compounds. XII. The Sulfonation of Styrene and of o-Phenylbutadiene.	A. P. Terentyev and A. V. Dombrovsky	1941	1875
22. γ -Bromopropylacetoacetic Ester.	V. F. Golovov	1947	1881
23. The Isomeric Transformations of Carbinols of the Furan Series. IV. The Synthesis of Aliphatic and Aliphatic-Aromatic γ -Ketoacids.	V. F. Kucherov	1951	1885
24. Investigations in the Domain of Amino Derivatives of the Heterocyclic Series. V. The Condensation Products of 5-Halogen-2-Aminopyridines with Acetoacetic Ester.	V. F. Kucherov	1957	1890
25. An Investigation of the Mechanism of the Claisen Rearrangement.	A. S. Pomenko and E. A. Sadovnikova	1965	1898
26. The Reactions of Methylene Bases of the Thiazole Series with α -Halogenated Ketones and other Halogen Derivatives.	F. S. Babichev	1971	1904
27. The Synthesis of Piazothiole (2,4-Benzo-1,2,5-Thiodiazole) and of its Derivatives.	A. M. Khaletsky and V. G. Pesin	1981	1914
28. Investigations of the Alkaloids of the Species of <i>Senecio</i> . VII. Alkaloids from <i>Senecio Renardi</i> .	A. Danilova and E. Konovalova	1989	1921
29. An Investigation of the Alkaloids of <i>Elaeagnus Angustifolia</i> . The Structure of Eleagnine.	G. P. Menshikov, E. L. Gurvich and G. A. Sazonova	1995	1927

THE JOURNAL OF GENERAL CHEMISTRY OF THE U. S. S. R.

Volume XX
October 1950

Publication of the Academy of Sciences of the U. S. S. R.

IN ENGLISH TRANSLATION

Copyright, 1952

CONSULTANTS BUREAU
152 West 42 Street
New York 18, N. Y.

Printed in France

Annual Subscription \$95.00
Single Issue: \$12.00

THE COLORS OF METAL CARBONYLS AND OF VARIOUS OTHER SUBSTANCES

D. A. Pospekhov

Kiev Forest Industry Institute

The present work is an attempt to review the colors of various complex compounds which have no outer layer. These include compounds formed by neutral atoms (A.A.Grinberg [6]), in particular the carbonyls, nitrosyl-carbonyls, nitrosyls, and amines of the metals. (Werner [3] called these substances coordination compounds of the elements.) Up to the present time, the color of these compounds has not yet been reviewed by any one, although, as is well known, the literature devoted to the relation between color and structure is a broad one.

The present work does not pretend to give an exhaustive explanation of this question, both because this represents a first attempt, and because data which refer to such compounds, as A.A.Grinberg [6] has noted, are still being accumulated. In addition, we must note the fact that the chromophore theory, based on the electron theory of valence, is in a state of development. In the field of inorganic compounds it is possible to determine the existence of various regularities in relation to several groups of substances [9, 12, 13, 23, 31, 39, 44, 49, 58, 105, 108, 107, 113, 125, 135, 141]. The field of organic compounds has been intensively and effectively studied with regard to color. We must note the investigations which are of most importance for the present work [7, 14, 16, 22, 23, 24, 25, 37, 41, 42, 64, 65, 102, 108, 144, 52], and the reviews [4, 17, 35, 66, 100]. Witzinger declared that he and Dilthey gave, with regard to organic compounds, "a complete theory of the relationship between structure and color, suitable for application" [4]. However, A.E.Porai-Koshits, in an introduction to the Russian translation of Witzinger's book [4], while noting the completeness of this theory, at the same time pointed out the weak spots which were present in it, the chief of which was the absence of a treatment of color on the basis of modern ideas of the dynamic structure of molecules. With regard to the later work of Ferster [41] and Lewis and Calvin [14], which represent several steps further along in comparison with the theory of Dilthey and Witzinger, A.E.Porai-Koshits [25] showed that these articles were "attempts to simplify, in a qualitative rather than a quantitative manner, on the basis of quantum-mechanical considerations, the basic rules which had already been discovered." In important monographs and reviews devoted to the consideration of the chemical problems from the point of view of modern ideas of the nature of the chemical bond and the structure of molecules, the questions regarding color are usually treated briefly [5, 8, 9, 12, 19, 20, 22, 31, 32, 58, 125, 133] or not at all [11, 38, 43, 128, 129, 143].

Taking into account all that has been said above, the present work took as its chief task the systematic review of the facts now known, and a determination of regularities.

In accordance with the viewpoint of the present work, we may note only a

few observations of Hieber [70,76,77,80,92] of which the most important is the fact that the colors of ethylenediamino and pyridine substituted carbonyls of iron are the more intense as the coordination unsaturation of the metal increases [77]. Here it is of interest to note that N.S. Kurnakov had already made a similar observation long ago (1897) [13]: the color of complex salts increased as water, ammonia, or other substances was added to them, i.e., as the coordination unsaturation was decreased. For example, $\text{CoCl}_3 \cdot 4\text{NH}_3$ is green, $\text{CoCl}_3 \cdot 5\text{NH}_3$ red, $\text{CoCl}_3 \cdot 6\text{NH}_3$ yellow, $\text{CoCl}_3 \cdot 4\text{NH}_3$ green, $\text{CoCl}_3 \cdot 4\text{NH}_3 \cdot \text{H}_2\text{O}$ violet-red, $\text{CoCl}_3 \cdot 4\text{NH}_3 \cdot 2\text{H}_2\text{O}$ red, $\text{PdCl}_2 \cdot \text{red-brown}$, $\text{PdCl}_2 \cdot 2\text{NH}_3$ yellow, $\text{PdCl}_2 \cdot 4\text{NH}_3$ colorless.

The present work is essentially close to the work of Blanshard [1,2] and of Ormont [18], who used the idea of effective atomic number. The former used it for the classification of carbonyls and the prediction of the formulas of still undiscovered volatile compounds of this type, the latter for the development of criteria for the stability of monomeric carbonyls of the metals. This same concept was applied by us to a consideration of the question of the stabilities [26] and the formulas of polymeric carbonyls of the metals [27].

As is well known, the effective atomic number (e.a.n.) is the name given to the number of electrons which enter into the configuration of the central atom of the complex compound [1, 136, 137, 138]. The difference between the e.a.n. of the central atom and the atomic number of the inert gas of the completed period in which the given metal is situated, according to the proposal of Ormont [18], is designated by Δ . In order to calculate the value of Δ it is assumed that the molecule of CO contributes two electrons to the central atom. The rule for this calculation is deduced from the fact that the monomeric carbonyls are volatile for those metal atoms which have $\Delta = 0$. The volatility is caused by the completion of the electron shell around the central atom [1, 2, 62, 87]. The main considerations about the character of the bonds in the metal carbonyls are confirmed to a great extent by this calculation (coordinate bond [1, 2, 3, 18, 46, 71, 72, 73, 87, 136, 137], donor-acceptor bond [138], triple bond of the type $\text{M} \equiv \text{C} - \text{O}$ [33, 34], single bond of the type $\text{M} - \text{C} \equiv \text{O}$ [33, 34], ordinary double bond [21, 33, 34, 59, 118],

In order to calculate the value of Δ for nitrosyls, we must assume that the molecule of NO which adds to the metal atom gives it three electrons [1, 87]. This can be deduced from the fact that $\text{Fe}(\text{CO})_2(\text{NO})_2$ [46] and $\text{Co}(\text{CO})_3\text{NO}$ [121] are volatile ($\Delta = 0$). (See the structural formulas below).

At present, the following volatile metal carbonyls are known: $\text{Cr}(\text{CO})_6$ [83, 98], $\text{Mo}(\text{CO})_6$ [83, 99, 122], $\text{W}(\text{CO})_6$ [83, 99], $\text{Fe}(\text{CO})_5$ [115, 120], $\text{Ni}(\text{CO})_4$ [119], $\text{Ru}(\text{CO})_5$ [110], $\text{Os}(\text{CO})_5$ [93]. These compounds are colorless. With respect to $\text{Fe}(\text{CO})_5$ we must note that this substance, if it is obtained in large quantities, is in appearance barely distinguishable from water [115]. In other investigations [54, 120], where the carbonyl was handled in small amounts, there were indications that it had a pale yellow color. This can be explained by the presence of the golden-yellow nonacarbonyl as impurity. This is very easily formed in the light according to the equation $2\text{Fe}(\text{CO})_5 \rightarrow \text{Fe}_2(\text{CO})_9 + \text{CO}$ [54, 115]. Summing up, we may conclude that the completeness of the electronic configuration of the central atom in a volatile carbonyl is the cause for the absence of color.

We may note further the inapplicability to these carbonyls of the ideas of the important chromophoric theories, to the effect that the accumulation of CO groups has a bathochromic effect. Those carbonyls in which a maximum number of these groups is attached to a single metal atom are likewise colorless (for comparison see in Table 1, the formulas of the polymeric carbonyls). The chromophore theories are based, for example, on such facts as these [4, 25]: $\text{CH}_3 \cdot \text{CO} \cdot \text{CO} \cdot \text{CH}_3$ is yellow, $\text{CH}_3 \cdot \text{CO} \cdot \text{CO} \cdot \text{CO} \cdot \text{CH}_3$ is orange yellow, $\text{C}_6\text{H}_5 \cdot \text{CO} \cdot \text{CO} \cdot \text{C}_6\text{H}_5$ is yellow, $\text{C}_6\text{H}_5 \cdot \text{CO} \cdot \text{CO} \cdot \text{CO} \cdot \text{C}_6\text{H}_5$ is golden yellow, $\text{C}_6\text{H}_5 \cdot \text{CO} \cdot \text{CO} \cdot \text{CO} \cdot \text{CO} \cdot \text{C}_6\text{H}_5$ is red. There are, however, cases where the accumulation of CO groups does not have an appreciable

bathochromic effect. For example, the tetramer of the lower carbon oxide, C_2O_2 :

$OC-C \begin{array}{c} CO \\ \diagup \quad \diagdown \\ CO \end{array} C \begin{array}{c} CO \\ \diagup \quad \diagdown \\ CO \end{array} C \begin{array}{c} CO \\ \diagup \quad \diagdown \\ CO \end{array} C=CO$ is golden yellow, [55]; triquinoyl, $(CO)_5 \cdot 7H_2O$ in ether solution, under the action of phosphoric anhydride, undergoes only yellowing [57].

All the polymers of metal carbonyls now known, with the exception of rhenium carbonyl $[Re(CO)_5]_2$ [91] are colored substances (Table 1). If we consider the colors of the carbonyls of one and the same metal, it is easy to see that the depth of color in them is greater the higher the negative value of Δ , calculated for the monomer, that is, the further the electron shell of the central atom of the monomer is from completion. (The sequence of arrangements of color with regard to depth was determined a long time ago [135] and is generally accepted: green-yellow, yellow, orange, red, violet, blue, green, black).

TABLE 1

Formula	Δ for monomer	Color	References
$[Fe(CO)_4]_3$ $Fe(CO)_5$	- 2 - 4	Green Red (in solution)	[54, 72, 75] [73, 75, 77, 81]
$[Co(CO)_4]_2$ $[Co(CO)_3]_4$	- 1 - 3	Orange Black	[122] [78, 122]
$[Re(CO)_5]_2$	- 1	Colorless	[91]
$[Ir(CO)_4]_2$ $[Ir(CO)_3]_n$	- 1 - 3	Greenish-yellow Yellow	[90, 93] [90]
$[Ru(CO)_4]_n$	- 2	Red-yellow	[110]

To Table 1 we must add two observations: 1) As can be seen, $Fe(CO)_3$ disappears from the general color picture. The cause for this lies in the fact that the red color observed must be ascribed not to this carbonyl, which up to the present time has not been isolated, but to some addition product, in which Δ is close to zero. We have an indication of this in the existence of compounds which have a red color: $Fe(CO)_3 \cdot C_5H_5N$ [71, 75], $Fe(CO)_3 \cdot H_2O$ [71], $Fe(CO)_3 \cdot CH_3OH$ [71], and $2Fe(CO)_3 \cdot CH_3CN$ [75]. In addition, we have evidence of the radical-like character of $Fe(CO)_3$ [71] as well as of the fact that it is stabilized by the formation of addition products [75]. 2) The polymerization coefficients, n , for iridium tricarbonyl and ruthenium tetracarbonyl are unknown. The values of n can be determined if we consider the relationship between n and Δ for the other carbonyls listed in the table with a definite molecular weight. This relationship has the following expression: $n + \Delta = 1$. Hence we obtain the formulas $[Ir(CO)_3]_4$ and $[Ru(CO)_4]_3$ [27].

The parallelism observed between the depth of color and the value of Δ , calculated for the monomer, leads to the supposition that the color must be ascribed to the monomer. Consequently, we must assume the presence of the equilibrium $[M(CO)_m]_n \rightleftharpoons nM(CO)_m$. From this point of view, the absence of color in the pentacarbonyl of rhenium can be explained by the practically complete displacement of the equilibrium to the left. A confirmation of this assumption can be seen in various data obtained during the determination of the molecular weight of the carbonyls. Thus, for $[Co(CO)_4]_2$, $M_{theor.} = 342$, while 328 was actually found [122]. Consequently, the carbonyl is 4.3% dissociated.

The assumption that this equilibrium exists may call forth the objection

that all the carbonyls of metals with magnetic susceptibility which have been investigated have been diamagnetic [$\text{Cr}(\text{CO})_6$, $\text{Mo}(\text{CO})_6$, $\text{Fe}(\text{CO})_5$, $\text{Fe}_2(\text{CO})_9$, $\text{Fe}_3(\text{CO})_{12}$, $\text{Ni}(\text{CO})_4$] [10, 30, 47, 51, 101, 133]. At the same time, in accordance with the Sidgwick-Bose rule [10] diamagnetism is possible for complex compounds under conditions in which $\Delta = 0$. (The Sidgwick-Bose rule is: the magnetic moment equals the total spin moment of that number of electrons which equals the difference between e.a.n. and the number of electrons closest to an inert gas [10].) There are, however, indications of exceptions to this rule: for instance the compounds $\text{K}_2[\text{Ni}(\text{CN})_4]$ and $\text{K}_4[\text{Co}(\text{CN})_6]$ [139], $\text{K}_3[\text{Co}(\text{CN})_5\text{CO}]$, $\text{K}_2[\text{Ni}(\text{CN})_3]$ [10], $\text{K}_2[\text{PdCl}_4]$, $\text{K}_2[\text{Pd}(\text{CN})_4]$, and $\text{K}_2[\text{Pd}(\text{NO}_2)_4]$ [95] are diamagnetic. It is necessary, in addition, to note Klemm's observation to the effect that this rule has no genuine theoretical foundation [10].

We shall turn our attention to the fact that for all the diamagnetic carbonyls, the e.a.n. of the monomers is an even number. In this connection it is possible to make the assumption that paramagnetic properties exist in these carbonyls in which the e.a.n. of the monomer is an odd number, for example in the tetracarbonyls of cobalt and iridium (e.a.n. 35 and 85, respectively). We must further assume that $[\text{Re}(\text{CO})_5]_2$ (Δ of the monomer = -1) must be diamagnetic, as it is colorless, and therefore, undissociated. In the dimer, $\Delta = 0$, as a two electron bond [10] is formed between the atoms of the metal. An investigation of the magnetic properties of these carbonyls is needed to decide the question of the correctness of these assumptions.

The products of addition to these monomeric carbonyls, in which $\Delta = 0$, are colored. These include $\text{Fe}(\text{CO})_5 \cdot 2\text{H}_2\text{O}$ [60, 61], $\text{Fe}(\text{CO})_5 \cdot \text{C}_2\text{H}_4(\text{NH}_2)_2$ [68], $\text{Fe}(\text{CO})_5 \cdot \text{HgCl}_2$ [94], $\text{Fe}(\text{CO})_5 \cdot 2\text{NH}_3$ [68, 74], $\text{Fe}(\text{CO})_5 \cdot \text{C}_6\text{H}_5\text{N}$ [68]. According to the formula, for all these substances, Δ for the central atom > 0 .

Thus, in all the compounds considered above, in which color is present, $\Delta_{\text{monomer}} \neq 0$. It is of interest to note that this is also true of free radicals. Lewis [15, 106] defined free radicals as molecules having an odd number of electrons, and noted that all the known free radicals, except for NO , were colored (with regard to the peculiarity of the structure of NO , see for example [2, 21, 33, 34, 36, 38, 126, 129]). NO , like all the free radicals which have been investigated with regard to magnetic properties, is paramagnetic [109]. It is not difficult to see that free radicals can have both negative and positive values of Δ . For example, in $\text{N}(\text{C}_2\text{H}_5)_4$ [124, 134] and NO_2 , the nitrogen has $\Delta = +1$, in ClO_2 the chlorine has $\Delta = +3$, in Ar_2N [145] and Ar_3C , Δ is -1. In metal ketyls, as in $(\text{C}_6\text{H}_5)_2\text{C}=\text{ONa}$ [38], the Δ of the carbon is also equal to -1. Further examples of this nature can be found by utilizing the data which exists, for example in the work of Shorygin [45], Walden [142], and Waters [38]. The so-called subcompounds [49] are always colored, like CaCl or Ar_3Pb , which are examples of this type. In a similar way, the blue color of solutions of the alkali metals in liquid ammonia can be explained if, following Kraus [103], we assume the presence in these solutions of the ions NH_3^{3-} or $(\text{NH}_3)_x^-$ (for nitrogen, $\Delta = +1$). It is of interest to note, in addition, the deep color of the ammoniacal salts $[\text{R}_3\text{N}]^+x^-$ (Witzinger [4]), where the nitrogen has $\Delta = -1$.

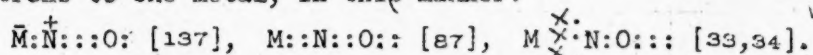
The definition of Lewis for radicals, as given above, does not correspond to the hexaamines of alkali-earth metals, which, according to Werner [3] are free radicals of salts of the type $[\text{M}(\text{NH}_3)_6]\text{I}_2$. Developing the point of view of Werner, we may say that the monomers of the metal carbonyls which have $\Delta < 0$, are also free radicals. This conclusion is strengthened by the fact that the carbonyl hydrides known at present, $\text{HCo}(\text{CO})_4$ [1, 53, 89], and $\text{H}_2\text{Fe}(\text{CO})_4$ [1, 57, 58, 87, 94] have acid properties.

The volatile nitrosyl-carbonyls $\text{Fe}(\text{CO})_2(\text{NO})_2$ [46] and $\text{Co}(\text{CO})_3\text{NO}$ [121] have a red color. The same color, apparently, is possessed by the volatile $\text{Co}(\text{NO})_3$, whose existence, however, has not been completely demonstrated [82]. To

the extent that the central atoms in these compounds have a value of $\Delta = 0$, the color can be explained by the assumption that the atoms of nitrogen have $\Delta = -1$, as can be seen from the suggested formula $(OC)_3CO \left[\overset{\cdot}{N}::O \right]$. This sort of addition of the NO molecule to the metal atom was accepted by Manchot [111] in his consideration of the structure of $(ON)_2FeSC_2H_5$. We can also assume another formula with a triple bond between the nitrogen and the metal $(OC)_3Co \left[\overset{\times}{\times}::N::O \right]$, where the nitrogen has $\Delta = +2$. Structures in which the octet configuration is not maintained are well known [21, 33, 38, 128, 129].

The deep (black) color of $Fe(NO)_4$ [112] can be explained by the combination of the bathochromic action of NO and the value $\Delta = +2$ for the iron atom. If we adhere to the opinion that this compound is a nitrosyl-hyponitrite $Fe(NO)_2N_2O_2$ [58, 118], then the iron has $\Delta = -2$. Similar conclusions hold also for the nitrosyl of ruthenium, $Ru(NO)_{4-5}$, which has a red color and is not volatile [110].

The formulas now known for metal nitrosyls provide that the NO molecule give up three electrons to the metal, in this manner:



Everything said above leads to the conclusion that the addition of CO to a metal results in a hypsochrome effect, and the addition of NO in a bathochrome effect. Further confirmation of the correctness of these conclusions is to be found in the comparison given below of the properties of carbonyl and nitrosyl complex metal salts of the platinum group (cf. Table 2, where data taken from Manchot's review [111] are listed).

TABLE 2

$RuCl_2$ - blackish blue	$RuCl_2 \cdot 2CO$ - yellow	$RuCl_2 \cdot (NO)_x$ - brown
$RuBr_2$ - blackish blue	$RuBr_2 \cdot 2CO$ - light ochre	$RuBr_2 \cdot NO$ - brown
RuI_2 - blackish blue	$RuI_2 \cdot 2CO$ - ochre	$RuI_2 \cdot NO$ - black
$PdCl_2$ - brown	$PdCl_2 \cdot CO$ - yellow	$PdCl_2 \cdot 2NO$ - blackish brown
$OsCl_2$ - brownish black	$OsCl_2 \cdot 3CO$ - colorless	$OsCl_2 \cdot (NO)_x$ - red brown
$IrCl_2$ - brown	$IrCl_2 \cdot 2CO$ - colorless	-
$PtCl_2$ - green	$PtCl_2 \cdot CO$ - yellow	-
$PtCl_2$ - green	$PtCl_2 \cdot 2CO$ - colorless	-
$PtBr_2$ - brown	$PtBr_2 \cdot CO$ - red	-
$PtBr_2$ - brown	$PtBr_2 \cdot 2CO$ - colorless	-

As can be seen from Table 2, the addition of CO to the halide results in a sharp intensification of the color in all cases. In this process, an increase in the number of CO molecules from one to two results in a further increase in color. The addition of NO has, in certain cases, a weak hypsochromic effect (RuI_2 , $RuBr_2$, $OsCl_2$), and in other cases a weak bathochromic effect (RuI_2 , $PdCl_2$). Consequently, we must conclude that the bathochromic properties of NO in general approximately overlap the increase of color, which is produced as a result of a decrease in the coordination unsaturation of the metal in these salts. For a judgment of the presence, even though to a slight extent, of bathochromic properties in CO in carbonyl complexes, we have no direct data. If such properties exist, they are very strongly covered by the hypsochromic effect of the decreased coordination unsaturation of the metal. We must also note that in the chemistry of organic dyes the existence of strong chromophoric properties has been found for nitrosyl groups, and of weak ones for carbonyl groups.

The amines of the alkali earth metals - the red brown $[Ca(NH_3)_8]$ [50, 104], the red $[Sr(NH_3)_8]$ [50, 103], the red $[Ba(NH_3)_8]$ [50, 63, 114] have $\Delta = -4$,

if we consider that the ammonia molecule gives up two electrons to the atom of metal.

The question of the composition of the amines of lithium and sodium has not been definitely decided. There are indications of the existence of $\text{Li}\cdot\text{NH}_3$, $\text{Li}(\text{NH}_3)_2$ [117], and $\text{Li}(\text{NH}_3)_4$ (?) [40, 82]. These substances are colored and not volatile. According to certain data, sodium ammine has the composition $\text{Na}\cdot 5\text{NH}_3$ [132], according to other data, $\text{Na}\cdot\text{NH}_3$ [98]. The latter formula is considered by various authors as already refuted [40, 131]. In any case, it can be seen from the formulas given that in them $\Delta \neq 0$. This fact is in harmony with the lack of volatility of these substances, and the existence in them of color.

The carbonyls of the alkali and alkali earth metals, if we judge by the structure $(\text{COK})_6$ [123] found for potassium carbonyl, are hexahydroxybenzates, and all of them therefore must have a white color. Of the known compounds of this type, LiCO and RbCO are white [127]. NaCO and KCO [97] have a white color with lilac and rose shadings respectively. $\text{Ca}(\text{CO})_2$ is cream-colored [127], $\text{Sr}(\text{CO})_2$ [130] and $\text{Ba}(\text{CO})_2$ [83, 114] are yellow. The yellow colors found must be ascribed to contamination.

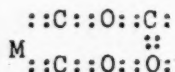
The nitrosyls NaNO and KNO [97] are white, slightly rose-tinted, and $\text{Ba}(\text{NO})_2$ is white [114]. The indications that NaNO and KNO are hyponitrites [97], were refuted on the basis of x-ray data [146]. The diamagnetic properties of NaNO , according to Pauling [21], indicate, apparently, the presence of an anion with the structure $[\text{:}\ddot{\text{N}}=\ddot{\text{O}}\text{:}]^-$. In this case, a completed octet configuration ($\Delta = 0$) is observed in NaNO . Therefore, these substances must have a white color in the pure form.

Let us turn to a consideration of the substituted monometal carbonyls, in which $\Delta = 0$. These substances are colored. Such, for example, are the substituted hexacarbonyls of chromium, molybdenum, and tungsten [83, 84], of the type of $\text{M}(\text{CO})_4(\text{C}_5\text{H}_5\text{N})_2$, where $\text{C}_5\text{H}_5\text{N}$ is pyridine, and of the type of $\text{M}(\text{CO})_3(\text{C}_5\text{H}_5\text{N})_3$, as well as of the derivative of nickel tetracarbonyl $\text{Ni}(\text{CO})_2\cdot\text{C}_{12}\text{H}_8\text{N}_2$ [79], where $\text{C}_{12}\text{H}_8\text{N}_2$ is orthophenanthroline, and of iron pentacarbonyl, $\text{Fe}(\text{CO})_3\cdot\text{C}_2\text{H}_4(\text{NH}_2)_2$ [78]. The presence of color can be explained by the fact that the electron configuration of the central atom is asymmetrical as a result of steric factors. The existence of the factors is apparently indicated by the fact that the displacement of the CO groups from the carbonyls by the action of amino compounds does not take place completely: three [83, 84] or two [79] such groups remain undisplaced. These groups are drawn together, and as a result they are able to interact, as is definitely shown by the formation of a cyclic structure. This is also indicated by several observations of Hieber [89, 71] made during an investigation of the reaction products of hydrochloric acid and $\text{Fe}_2(\text{CO})_5(\text{NH}_2\text{C}_2\text{H}_4\text{NH}_2)_2$. The formation of substances has been noted which are reminiscent of rhodizonic acid

and croconic acid $\text{OC} \begin{array}{c} \text{CO-C-OH} \\ \parallel \\ \text{CO-C-OH} \end{array}$ [85]. On the other hand, it is necessary to note

the possibility of a certain polymerization of the CO according to the scheme $n\text{CO} \rightleftharpoons \text{C}_n\text{O}_n$, as suggested by Berthelot [48]. This possibility was taken into account by us when we considered the mechanism of the formation of metal carbonyls [28] and the mechanism of catalytic syntheses from CO and H_2 [29].

The possibility of the existence of such structures of the volatile metal carbonyls, in which only part of the CO groups are bound to the central atom, while the others form a bridge between those directly added, was proposed by Blanshard [1], as in the example:



If we assume that the metal carbonyls have structures of the type

$\begin{array}{c} \text{C=O} \\ \diagup \quad \diagdown \\ \text{M} \end{array}$
 or
 $\begin{array}{c} \text{C=O} \\ \diagup \quad \diagdown \\ \text{M} \quad \text{C=O} \\ \diagdown \quad \diagup \\ \text{C=O} \end{array}$
, then it is easy to see that in these cases, the metal atom

acquires a total of two electrons instead of four and six respectively. The presence of such structures in the substituted metal carbonyls listed above, as well as in the polymeric carbonyls, where steric factors must play an essential role, must be considered probable on the basis of the considerations given. In this case, the color of such compounds can be explained by the fact that the metal atoms in them have $\Delta < 0$. Thus, for example, in $\text{Ni}(\text{CO})_4 \cdot \text{C}_{12}\text{H}_8\text{N}_2$, $\Delta = -2$, in $\text{Mo}(\text{CO})_3(\text{C}_5\text{H}_5\text{N})_3$, $\Delta = -4$, etc.

In a similar way, we can explain the colors of $\text{Fe}_2(\text{CO})_9$ [54] and $\text{Ru}_2(\text{CO})_9$ [110]. These compounds are not volatile.

We must note that the idea that the lack of completeness of the electron shell is the factor which determines the presence of color has been expressed by a number of authors who considered the colors of ions. [31, 105, 107, 113, 125, 141]. It has been found that this phenomenon is encountered (predominantly [39]) with elements which are situated in the middle portions of the great periods of the Mendeleev System. Thus, the metals have been noted from V to Ni, from Nb to Pd, from Ta to Pt [113]. There are indications also of a wider range of metals: Ti - Cu, Zr - Ag, and Hf - Au [125].

Further investigations in the domain of the substances reviewed by us are needed to shed light on the presence of obacurities.

SUMMARY

The colors of metal carbonyls have been considered, along with some of their derivatives and addition products, as well as of the metal nitrosyl-carbonyls, nitrosyls, and amines. During this review, it has been shown that all the known cases of color in these compounds may be explained by the presence in them of atomic structures which satisfy the conditions $\Delta \neq 0$, where Δ is the difference between the number of electrons entering into the configuration of the given atom, and the atomic number of the inert gas which concludes the period in which the given element is situated.

LITERATURE CITED

- [1] A. Blanshard, *Prog. Chem.* 7, 1464 (1938); *Chem. Rev.*, 21, 3 (1937).
- [2] A. Blanshard, *Prog. Chem.*, 10, 815 (1941); *Chem. Rev.*, 26, 409 (1940).
- [3] A. Werner, *New Viewpoints in the Domain of Inorganic Chemistry*, Leningrad, 255-259 (1936).
- [4] R. Witzinger, *Organic Dyestuffs*, United. Sci. Tech. Press, 4, 14, 17, 20 (1936).
- [5] M. V. Volkenshtein, *The Structure of Molecules*, Moscow-Leningrad, 115-119 (1947).
- [6] A. A. Grinberg, *Introduction to the Chemistry of Complex Compounds*, Moscow, 18 (1945).
- [7] V. A. Izmailsky and Coworkers, *J. Gen. Chem.* 7, 508, 513, 523 (1937); 8, 1730 (1938); 9, 647, 1007 (1939); *Proc. Acad. Sci. USSR*, 14, 17 (1937); 20, 669, 675 (1938); 26, 906, 912 (1940); 28, 622 (1940).
- [8] A. I. Kiprianov, *Electron Theory in Organic Chemistry*, Kiev, 116-126 (1947).
- [9] V. Klemm, *Magnetochemistry*, Moscow, 142 (1939).
- [10] V. Klemm, *Magnetochemistry*, Moscow, 171-177 (1939).

[11] V.N.Kondratyev, The Structure of Atoms and Molecules, Moscow-Leningrad, (1946).

[12] R.Kreman, M.Pestemer, The Relationship Between Physical Properties and Chemical Structure, Moscow-Leningrad, 106-115 (1939).

[13] N.S.Kurnakov, J.Russ.Chem.Soc., 29, 706 (1897); Z. anorg. u. algem. Chem., 17, 207 (1898).

[14] G.N.Lewis, Calvin, Prog. Chem., 10, 32 (1941); Chem. Rev., 25, 273 (1939).

[15] G.N.Lewis, Calvin, Prog. Chem. 10, 75 (1941).

[16] K.N.Merder, Trans. Leningrad. Chem.-Tech.Inst., 8, 42 (1940).

[17] N.N.Orlov, Progress in the Field of Dyes and Their Intermediates, Kharkov-Kiev, 223-328 (1936).

[18] V.F.Ormont, J.Phys.Chem. 11, 274 (1938); 12, 259 (1938); Acta phys.-chim., 9, 885 (1938).

[19] B.F.Ormont, Chemistry and the Structure of Materials, United. Sci. Tech. Press, 322-325, 354, 355 (1934).

[20] L.Pauling, The Nature of the Chemical Bond (Russ.Ed.) Moscow-Leningrad, 126 (1947).

[21] L.Pauling, The Nature of the Chemical Bond, Op.cit., 247-250, 261-270.

[22] L.Pauling, Prog.Chem., 7, 1312 (1938).

[23] M.Pestemer, Prog. Chem. 6, 1235 (1937); Angew.Chem., 50, 548 (1937).

[24] P.I.Petrenko-Kritchenko, J.Gen.Chem. 3, 587 (1933); 4, 885 (1934); 10, 1305 (1940); Ber., 66, 1049, 1771 (1933).

[25] A.E.Porai-Koshits, J.Russ.Chem.Soc., 42, 1237 (1910); Proc.Acad.Sci. USSR, 28, 135 (1940).

[26] D.A.Pospekhov, J.Phys.Chem. 21, 11 (1947).

[27] D.A.Pospekhov, J.Gen.Chem., 18, 2045 (1948).

[28] D.A.Pospekhov, J.Gen.Chem., 18, 610 (1948).

[29] D.A.Pospekhov, Coll. Sci. Res. Papers, Kiev. Tech. Inst. Leather-Footwear Ind., 3, 261 (1940); Chem. Ref. J., 5, 12 (1941); Chem. Abs., 37, 4359 (1943).

[30] P.Selwood, Prog.Chem., 15, 149-169 (1946).

[31] Ch. U.Stillwell, Prog.Chem., 6, 1186 (1937).

[32] Ya.K.Syrkin, M.E.Dyatkina, The Chemical Bond and the Structure of Molecules. Moscow-Leningrad., 527-528 (1946).

[33] Ya.K.Syrkin, M.E.Dyatkina, Op.Cit., 166, 167, 306, 307, 430-440.

[34] Ya.K.Syrkin, M.E.Dyatkina, J.Gen.Chem., 16, 354 (1946); Acta phys.-chim., 20, 137 (1945).

[35] A.N.Terenin, The Photochemistry of Dyes and Related Organic Compounds, Moscow-Leningrad, 23-54 (1947).

[36] U.Waters, The Chemistry of Free Radicals, Moscow, 12, 38, 73, 90, 91 (1948).

[37] V.N.Ufimtsev, J.Gen.Chem. 11, 845 (1941).

- [38] J.U.Wheland, The Theory of Resonance and Its Application to Organic Chemistry, (Russ. ed.) Moscow, 59-64 (1948).
- [39] Fajans, Prog. Phys.Chem. 2, 333 (1925).
- [40] K. Fernelius, D. Batt, Prog. Chem. 7, 872 (1938); Chem.Rev., 20, 195 (1937).
- [41] Ferster, Prog.Chem., 9, 71 (1940); Z. Elektrochem., 45, 548 (1939).
- [42] A.A.Kharkharov, Trans. Leningrad Chem.Tech.Inst., 7, 156 (1939).
- [43] V.Huckel, The Theoretical Foundations of Organic Chemistry, Leningrad 1 (1935); 2, (1936).
- [44] R.Schwartz, Prog. Inorg.Chem., State Sci.-Tech. Press, 17-22 (1931).
- [45] P.P.Shorygin, Prog. Org. Chem., United Sci.-Tech. Press, 48-69 (1932).
- [46] J.S.Anderson, Nature, 130, 1002 (1932); Z. anorg. allgem. Chem., 208, 238 (1932).
- [47] Berkmann, Zocher, Z. phys. Chem., 124, 318 (1926).
- [48] Berthelot, Comptes Rend., 82, 1362 (1876); 119, 954 (1891); 142, 533 (1906); Ann. chim. et phys. (5), 10, 72 (1877); (6), 24, 126 (1891); (8) 9, 173 (1906).
- [49] W.Biltz, Z. allgem. anorg. Chem., 127, 169 (1923).
- [50] W.Biltz, Hüttig, Z. allgem. anorg. Chem., 114, 241 (1920).
- [51] Bose, Z. phys., 65, 677 (1930).
- [52] Burawoy, Ber., 63, 3155 (1930); 64, 462 (1931); 64, 1633, (1931); 65, 971, 947, (1932); 66, 229 (1933).
- [53] Coleman, Blanchard, J.Am.Chem.Soc., 58, 2160 (1936).
- [54] Dewar, Jones, Proc. Royal Soc., London, A, 76, 558 (1905); 79, 66 (1907).
- [55] Diels, Beckmann, Tonnies, Ann., 439, 76 (1924).
- [56] H.J.Emelius, J.S.Anderson. Modern Aspects of Inorganic Chemistry. N.Y., (1938), 407-431.
- [57] Feigl, Krumholz, Monatsh., 59, 314 (1932).
- [58] Feigl, Krumholz, Z. allgem. anorg. Chem., 215, 242 (1933).
- [59] Ferreira da Silva, Bull. Soc. chim., (3), 15, 835 (1896).
- [60] H.Freundlich, Cuy, Ber., 56, 264 (1923).
- [61] H.Freundlich, Malchow, Z. allgem. anorg. Chem., 141, 328 (1924).
- [62] Gmelins Handbuch der anorganischen Chemie. Berlin, 20, 91 (1927).
- [63] Guntz, Mentrel, Bull. Soc. chim., (3), 29, 585 (1903).
- [64] Hantzsch, Ber., 52, 509 (1919); 54, 2569 (1921); 65, 1059 (1932).
- [65] Hantzsch, Burawoy, Ber., 66, 1435 (1933).
- [66] Henrich. Theorien der organischen Chemie. Braunschweig. 331-413 (1924).
- [67] Henle, Ann., 350, 335 (1906).
- [68] Hieber, Sonnekalb, Ber., 61, 2421 (1928).
- [69] Hieber, Sonnenkalb, Ber., 61, 558 (1928).
- [70] Hieber, Bader, Ber., 61, 1717 (1928).

- [71] Hieber, Naturwissenschaften, 18, 33 (1930).
- [72] Hieber, Leutert, Naturwissenschaften, 19, 360 (1931).
- [73] Hieber, Becker, Ber., 63, 1405 (1930).
- [74] Hieber, Sonnekalb, Becker, Ber., 63, 973 (1930).
- [75] Hieber, Vetter, Ber., 64, 2340 (1931).
- [76] Hieber, Mühlbauer, Ber., (72) 65, 1085 (1932).
- [77] Hieber, Leutert, Ber., 64, 2832 (1931).
- [78] Hieber, Mühlbauer, Ehmann, Ber., 65, 1090 (1932).
- [79] Hieber, Leutert, Z. allgem. anorg. Chem. 204, 145 (1932).
- [80] Hieber, Vetter, Z. allgem. anorg. Chem., 212, 145 (1933).
- [81] Hieber, Kaufmann, Z. allgem. anorg. Chem., 204, 174 (1932).
- [82] Hieber, Anderson, Z. allgem. anorg. Chem., 211, 132 (1933).
- [83] Hieber, Romberg, Z. allgem. anorg. Chem. 221, 321, 332 (1935).
- [84] Hieber, Mühlbauer, Z. allgem. anorg. Chem., 221, 337 (1935).
- [85] Hieber, Sitzungsber. Heidelberg Akad., 3, 4 (1929); Chem. Zentr., 1, 3648 (1929).
- [86] Hieber, Z. angew. Chem., 49, 463 (1936).
- [87] Hieber, Z. Elektrochem., 43, 390 (1937).
- [88] Hieber, Schulten, Z. allgem. anorg. Chem. 232, 29 (1937).
- [89] Hieber, Fack, Z. allgem. anorg. Chem., 236, 83 (1936).
- [90] Hieber, Lagally, Chem. Abs. 35, 7860 (1941); Z. allgem. anorg. Chem., 245, 321 (1940).
- [91] Hieber, Fuchs, Chem. Abs., 37, 3681 (1943); Chem. Zent., 1, 2509 (1942).
- [92] Hieber, Stallmann, Chem. Zentr., 1, 1870 (1943); Ber., 75, 1472 (1943).
- [93] Hieber, Stallmann, Chem. Abs., 38, 1967 (1944); Z. Elektrochem., 49, 288 (1943).
- [94] Hock, Stuhlmann, Ber., 61, 2098 (1928); 62, 431 (1929).
- [95] Janes, J. Am. Chem. Soc., 57, 471 (1935).
- [96] Joannis, Ann. chim. phys. (8), 11, 101 (1907).
- [97] Joannis, Ann. chim. phys. (8), 7, 96 (1906).
- [98] Job, Cassal, Bull. Soc. chim., (4), 41, 814, 1041 (1927); Comptes rend., 183, 392 (1926).
- [99] Job, Rouvillois, Comptes rend., 187, 564 (1928).
- [100] Kaufmann, Beziehungen zwischen physikalischen Eigenschaften und chemischen Konstitution. Stuttgart (1920).
- [101] Klemm, Jacobi, Tilk, Z. allgem. anorg. Chem., 201, 1 (1931).
- [102] König, J. prakt. Chem., (2), 112, 15 (1926).
- [103] Kraus, J. Am. Chem. Soc., 36, 864 (1914).
- [104] Kraus, J. Am. Chem. Soc., 30, 653 (1908); 44, 1237 (1922).
- [105] Ladenburg, Z. Elektrochem., 26, 262 (1920).

- [106] G.N.Lewis, J.Am.Chem.Soc., 38, 762 (1916).
- [107] G.Lea, Z. allgem. anorg. Chem., 2, 312 (1895); 12, 340 (1896).
- [108] Lifschitz, Ber., 52, 1919 (1919); 58, 2434 (1925); 64, 161 (1931).
- [109] Lips, Helv. phys. Acta., 7, 663 (1934); 8, 247 (1935).
- [110] Manchot, W.J. Manchot, Z. allgem. anorg. Chem., 226, 385 (1936).
- [111] Manchot, Ann., 470, 261 (1929).
- [112] Manchot, Ann., 470, 275 (1929).
- [113] Meisenheimer, Z. phys. Chem., 97, 304 (1921).
- [114] Mentrel, Comptes rend., 135, 740 (1902).
- [115] Mittasch, Z. angew. Chem., 41, 827 (1928).
- [116] Moeller, J.Chem. Education, 23, 542 (1946).
- [117] Moissan, Comptes rend., 127, 685 (1898); Bull. Soc. chim., (3), 21, 904 (1899).
- [118] L.Mond, Nasini, Gazz. chim. ital., 21, 1, 501 (1891); Atti accad. naz. Lincei., 7, 411 (1891).
- [119] L.Mond, Langer, Quincke, J.Chem.Soc., 57, 749 (1890).
- [120] L.Mond, Quincke, J.Chem.Soc., 59, 604, 1090 (1891).
- [121] R.Mond, Wallis, J.Chem.Soc., 121, 32 (1922).
- [122] L.Mond, Hirtz, Cowap, J.Chem.Soc., 97, 798 (1910).
- [123] Nietzsche, Benckiser, Ber., 18, 1883 (1885).
- [124] Palmaer, Z. Elektrochem., 38, 729 (1902).
- [125] Parsons, J.Chem.Education, 25, 207 (1948).
- [126] Pauling, J.Am.Chem.Soc., 53, 3225 (1931).
- [127] Pearson, Nature, 131, 166 (1933).
- [128] Remick, Electronic Interpretation of Organic Chemistry, N.Y., 1943, 173-187.
- [129] Rice. Electronic Structure and Chemical Binding. N.Y., (1940), 347.
- [130] Roederer, Comptes rend., 140, 1252 (1905); Bull. Soc. chim. (3), 35, 715 (1906).
- [131] Ruff, Geisel, Ber., 39, 828 (1906).
- [132] Ruff, Zedner, Ber., 41, 1948 (1908).
- [133] Selwood, Magnetochemistry. New York, 128-179 (1943).
- [134] Schlubach, Ber., 53, 1689 (1920).
- [135] Schütze, Z. phys. Chem., 2, 109 (1892).
- [136] Sidgwick, Trans. Faraday Soc., 19, 469 (1923); Z. Elektrochem., 34, 447 (1928).
- [137] Sidgwick, Bailey. Proc. Royal Soc. (London), A, 144, 521 (1934).
- [138] Sidgwick, J.Chem.Soc., 433 (1941).
- [139] Szego, Cambi, Ostinelli, Gazz. chim. ital., 60, 926 (1930); Ber., 64, 2591 (1931).

- [140] Sutton, Bentley, Nature, 130, 314 (1932).
- [141] J. Thomsen, Z. allg. anorg. Chem., 10, 155 (1895).
- [142] Walden. Chemie der freien Radikale. Leipzig (1924).
- [143] Watson. Modern Theories of Organic Chemistry. Oxford (1941).
- [144] Witzinger, Ber., 60, 1377 (1927).
- [145] Wieland, Ann., 381, 200 (1911); 392, 127 (1912); Ber., 44, 2550 (1911); 45, 2600 (1912).
- [146] Zintl, Hardner, Ber., 66, 760 (1933).

Received January 4, 1949.

ALUMINUM-FLUORIDE COMPLEXES IN SOLUTION

K. E. Kleiner

Institute of General and Inorganic Chemistry of the Academy of Sciences
of the Ukrainian SSR

Among the considerable number of individual compounds of aluminum fluoride with the fluorides of other metals, there are compounds like, for example, cryolite, which are undoubtedly complex, and compounds which more or less approximate, by the character of their dissociation in solution, free salts.

We did not find in the literature any direct reports on the energy of the chemical bond between aluminum and fluorine in these compounds. We could find only isolated comparative characteristics.

Thus, the complex fluoride compounds of aluminum (Na_3AlF_6) are somewhat more stable than the corresponding compounds of trivalent iron [1], considerably more stable than the compounds of magnesium, and of the same order of stability as the complex fluoride compounds of beryllium (Na_2BeF_4) [2].

Neither is there in the literature any attempt to determine quantitatively the bond between the individual compounds in as complete a series of fluoride complex ions of aluminum as possible (AlF^{2+} , AlF_2^+ , ... AlF_6^{3-}), although it is acknowledged that in a solution of complex ions the number of coordinated addends of the fluorine can be not only greater but also less than three [3].

Such a bond can be determined by starting with the value of the instability constant of the simplest alumino-monofluoride complex ions, AlF^{2+} .

As A.K. Babko has shown, there is a simple relation [4,5] between the values of the instability constant of complex ions with various numbers of addends.

Therefore, from the value of the instability constant of the simplest complex ion, which is determined with much more ease than the value of the constant of the more complicated ions, we can compute the corresponding values for the entire series of complex ionic forms.

Thus, we can obtain, on the one hand, a quantitative characteristic of the instability of different complexes, and on the other hand a picture of the behavior of the complex ions in solution (at a concentration at which one or another complex group predominates).

This method has been used in our laboratory in a series of researches [4,5,6,7]. In particular, we applied it to the investigation of complex-formation between the ions of ferric iron and fluorine in aqueous nitric acid solution [8]. From the data obtained, it followed, that at a concentration of free fluoride ions equal to 0.0025 g-ions per 1 liter, the concentration of electrically neutral FeF_3 molecules must predominate in the solution, while the total concentration of all the cations of the forms (FeF^{3+} , FeF^{2+} , FeF^+) must be equal to the total concentration of the anion forms (FeF_4^- , FeF_5^{2-} , FeF_6^{3-}).

Therefore, when such a solution is electrolyzed in a U-shaped vessel, the

catholite and the anolyte must be almost the same, and during the process there must be a very slight enrichment with complex ions of iron.

It has been found experimentally that this is observed at concentrations of free fluoride ions equal to 0.002 g-ions per liter, which is close to that computed.

Similar results have been obtained in the investigation of solutions of iron-thiosulfate complexes [5].

Consequently, we must consider that the relationships mentioned above between the values of the stepwise instability constants are fairly close to the actual, and give a general picture of the character of the equilibrium in such solutions.

In the present paper, we give the results of determinations of the values of the instability constants of the simplest alumino-monofluoride complex ions AlF^{2+} in aqueous nitric acid solution. We shall give the computed values, obtained by the relationship cited above, for the instability constants of other, more complicated, complex forms (AlF^{2+} , ..., AlF_5^{2-}).

On the basis of these values, we calculated the relationship between the concentration of one or another form of complex alumino-fluoride ions and the concentration of the fluoride ions in the solution.

For the investigation, we utilized a colorimetric method. However, the colorimetric investigation was made very difficult in the case where there were no color reactions of the aluminum ion with inorganic reagents, and the extent of the characteristic color reactions with organic reagents was limited by the fact that the existence of these reactions was connected with the introduction into the solution of such reagents as the acetate, carbonate, and hydroxide of ammonia, i.e., of components which did not have a direct relation to the reaction under investigation. During this, the pH of the medium increased to such an extent that it could lead to the formation of basic salts of aluminum.

Therefore we avoided the use of organic reagents, and chose another method, which is given in what follows.

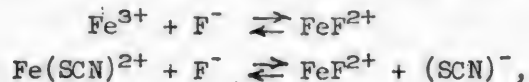
In a system which contains component A, and components B and C reacting with it, there are also, as a result, the products of their interaction, AB and AC. In such a system, a definite equilibrium exists, determined chiefly by the active concentrations of components A, B, and C and by the dissociation constants of AB and AC (under the condition that the other physical and chemical parameters remain unchanged).

If to this system we add a fourth component, D, which reacts with components C and with AC, to form DC, then a new condition of equilibrium arises, different from the previous one. If any kind of property of these systems, connected with the equilibrium condition, can be measured, and the initial (total) concentrations of A, B, C, and D and the dissociation constants of AB and AC are known, then it is obvious that the dissociation constant of DC can be calculated.

As a triple system (A - B - C) we chose the system $\text{Fe}(\text{NO}_3)_3$ - KSCN - NaF (in aqueous nitric acid solution), which had already been investigated previously [6].

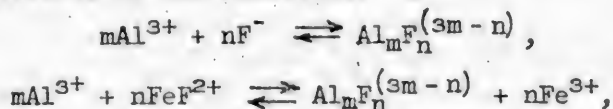
If to a solution of $\text{Fe}(\text{NO}_3)_3$ and KSCN, NaF is added, then, as is known, the intensity of the color, and consequently the concentration of iron-thiocyanate ions, is diminished.

This is the result of the formation of the colorless ferric iron-fluoride complex ions:



which are considerably more stable (approximately 1000 times) than the iron-thiocyanate ions [5,6,8].

If to this solution any salt of aluminum is added (component D corresponding to what is said above) then the reverse process will be observed - an increase in the intensity of the color, which is the result of the formation of alumino-fluoride complexes. During this process, the concentration of the fluoride ions decreases, and the concentration of the iron ions increases according to the equations for the equilibria of the reactions:



as a result of which the concentration of colored iron-thiocyanate ions is increased.

It is obvious that a change in the concentration of iron-thiocyanate ions can be measured colorimetrically, and depends, when the other conditions are maintained, on the concentration of aluminum salt, and on the ratios of the values of the instability constants of the complex ions.

Seeing that the instability constants of the complex ions $\text{Fe}(\text{SCN})^{2-}$ and FeF^{2-} are known [5,6], while the salt concentrations may be chosen arbitrarily, it is possible to determine the value of the instability constant of the alumino-fluoride complex ions.

Materials and Technique of Work

The preparations of $\text{Fe}(\text{NO}_3)_3$, $\text{Al}(\text{NO}_3)_3$, KSCN, and NaF were purified, and their solutions in 0.1 N nitric acid were prepared and determined in the manner previously described [a].

This experiment, like the previous one, was carried out with the measurement and comparison of the optical density of the solutions in a photocolormeter (compensation by means of a diaphragm). Light filter green.

To determine the value of the instability constant of aluminum monofluoride complex ions AlF^{2-} , it was necessary to select such concentrations of $\text{Al}(\text{NO}_3)_3$ and NaF that it would be known beforehand that only these aluminum-monofluoride complex ions would be formed in solution, and not more complicated ones.

We determined the composition of the complex ions in the solution by the variation method of Job [9], which we had previously used.

The relationship between the change in the property of the system (intensity of color) and the molar ratio of $\text{NaF}/\text{Al}(\text{NO}_3)_3$ was determined by the intensity of the color of a number of solutions, one series of which contained $\text{Fe}(\text{NO}_3)_3$, KSCN, and NaF, and the other series, in addition to these salts, $\text{Al}(\text{NO}_3)_3$.

We have already reported the fact that the velocity of the reaction between $\text{Al}(\text{NO}_3)_3$ and NaF is fairly low, and that the reaction attains an equilibrium condition after approximately a day [10].

This can be seen after the addition of the aluminum nitrate by the slow intensification of the color of the iron-thiocyanate solutions containing sodium fluoride.

This fact led to the result that the measurement of the optical density both for a definite composition as well as for a definite value of the instability constant could be carried out only a day after the solutions of $\text{Al}(\text{NO}_3)_3$, NaF, and $\text{Fe}(\text{NO}_3)_3$ were mixed.

The method of carrying out the experiment was as follows:

The solutions of aluminum nitrate and sodium fluoride of the same molar concentration (0.001 mole per 1 liter) were mixed, according to Job's method. The total volume of these solutions was always 20 ml. To mixtures prepared in this manner, there were added a solution of ferric nitrate and 0.1 N nitric acid (the original solutions of $\text{Al}(\text{NO}_3)_3$, NaF , $\text{Fe}(\text{NO}_3)_3$, and KSCN were, as indicated above, 0.1 N with regard to HNO_3).

At the same time, another series of solutions was prepared, but without aluminum nitrate. The concentration of $\text{Fe}(\text{NO}_3)_3$ in all the mixtures of both series was the same, while the concentration of NaF in any mixture of one series corresponded to the same concentration in any mixture of the other series.

A day after the preparation of both series of mixtures the same volume of a solution of potassium thiocyanate was added to them.

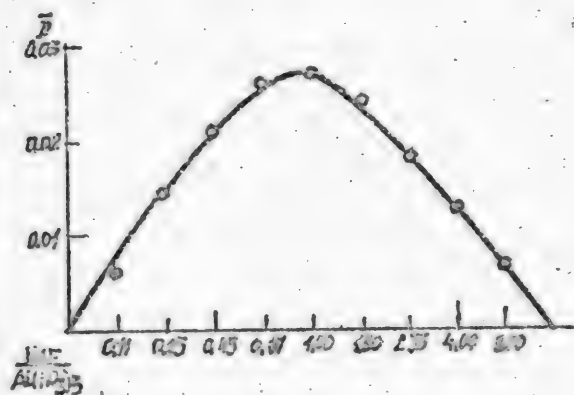


Fig. 1.

Thus, the total (initial) concentration of KSCN , as well as of $\text{Fe}(\text{NO}_3)_3$ was identical in all solutions of both series.

The final volume of each mixture was always 50 ml. The solutions were kept in a dark place both before and after the addition of KSCN . The measurements of optical density were carried out 4 to 6 hours after the addition of the KSCN solution, i.e., 26 to 30 hours after the mixing of the solutions of $\text{Al}(\text{NO}_3)_3$ and NaF , thus permitting complete certainty of the fact that equilibrium was attained in the system [10].

The experimental results are collected in Table 1, and in the graph of Fig. 1 the equimolecular ratio $\text{NaF}/\text{Al}(\text{NO}_3)_3$ is plotted against the difference in optical densities (ΔD) of the systems $\text{Al}(\text{NO}_3)_3 - \text{NaF} - \text{Fe}(\text{NO}_3)_3 - \text{KSCN}$ and $\text{NaF} - \text{Fe}(\text{NO}_3)_3 - \text{KSCN}$.

As is known, the composition of the compound in solution corresponds, according to Job, to the ratio of molar concentrations of the components of the reaction at which the greatest change in properties is observed.

The experimental results show that the maximal intensification of color (i.e., the greatest formation of ferri-thiocyanate, and therefore, in accordance with what has been said above, also of the alumino-fluoride complexes) is observed at an $\text{Al}:\text{F}$ ratio of 1 (Experiment 9).

Consequently, the complex AlF^{2+} ions are formed at an NaF concentration of the order of 10^{-4} mole or an F^- concentration of the order of 10^{-6} and less g-ions in 1 liter.

Instability Constants of the Complex Ions AlF^{2+}

In order to calculate the equilibrium concentrations of the components, starting with the expression for the instability constant

$$K_{\text{AlF}^{2+}} = \frac{[\text{Al}^{3+}][\text{F}^-]}{[\text{AlF}^{2+}]}, \quad (1)$$

TABLE 1

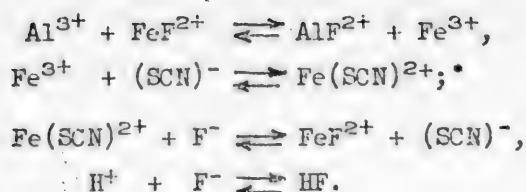
$[\text{Fe}(\text{NO}_3)_3] = 20.4 \cdot 10^{-5}$; $[\text{KSCN}] = 97.5 \cdot 10^{-5}$; $[\text{Al}(\text{NO}_3)_3] + [\text{NaF}] = 40 \cdot 10^{-5}$
mole in 1 liter

Expt. No.	Volume of solution (ml)		$\frac{\text{NaF}}{\text{Al}(\text{NO}_3)_3}$	Extinction of solutions	Difference between extinctions, \bar{D}
	NaF	$\text{Al}(\text{NO}_3)_3$			
1	2	18	0.11	0.2997	0.0064
2	2	—	—	0.2933	
3	4	16	0.25	0.2930	0.0143
4	4	—	—	0.2787	
5	6	14	0.43	0.2869	0.0209
6	6	—	—	0.2660	
7	8	12	0.67	0.2819	0.0254
8	8	—	—	0.2565	
9	10	10	1.00	0.2725	0.0272
10	10	—	—	0.2453	
11	12	8	1.50	0.2604	0.0238
12	12	—	—	0.2366	
13	14	6	2.33	0.2457	0.0180
14	14	—	—	0.2277	
15	16	4	4.00	0.2362	0.0129
16	16	—	—	0.2333	
17	18	2	9.00	0.2268	0.0068
18	18	—	—	0.2200	

it is necessary to carry out a series of computations, taking into account the fact that only one value, the concentration of $\text{Fe}(\text{SCN})^{2+}$, can be determined experimentally under our conditions. As the experiment was carried out with such a complicated system as $\text{Fe}(\text{NO}_3)_3 - \text{KSCN} - \text{Al}(\text{NO}_3)_3 - \text{NaF}$ in aqueous nitric acid solution, it is imperative to take into account the following chief equilibria:



The number of coordinated ions depends on the concentration of fluoride or thiocyanate. At such low concentrations as existed in the solutions under investigation, it was chiefly the simplest complex ions that were formed.



The values of the instability constant of the complex ions $\text{Fe}(\text{SCN})^{2+}$ and FeF^{2+} were previously determined in our laboratory during an investigation of the systems $\text{Fe}(\text{NO}_3)_3 - \text{KSCN}$ and $\text{Fe}(\text{NO}_3)_3 - \text{KSCN} - \text{NaF}$ in aqueous nitric acid solution. They are equal respectively to $4 \cdot 10^{-3}$ [5] and $5 \cdot 10^{-6}$ [8]. The value of the dissociation constant of HF is also known, and is equal to $1 \cdot 10^{-3}$ [11].

The independent and known variables include the salt concentrations, which can be chosen arbitrarily.

As all the solutions contain 0.1 mole of HNO_3 per 1 liter, slight changes in the concentrations of the salts, despite the fact that they are strong electrolytes, cannot essentially influence the ionic strength of the solutions, which may be considered constant ($\mu \approx 0.1$). Because of this fact, there is no great change in the activity coefficients even at different ratios of the concentrations of components.

As an example, we shall give the method for the computation of the value of a constant.

In the equilibrium $[\text{NaF}] = [\text{HF}] + [\text{F}^{-}] + [\text{FeF}^{2+}] + [\text{AlF}^{2+}]$ (II) only the initial concentration of NaF is known. In order to calculate $[\text{AlF}^{2+}]$ it is necessary to compute the equilibrium concentrations of the other three components. The concentration of FeF^{2+} can be computed from the equilibrium $[\text{Fe}(\text{NO}_3)_3] = [\text{Fe}^{3+}] + [\text{Fe}(\text{SCN})^{2+}] + [\text{FeF}^{2+}]$, in which $[\text{Fe}^{3+}]$ and $[\text{Fe}(\text{SCN})^{2+}]$ are unknown. However, the concentration of $\text{Fe}(\text{SCN})^{2+}$ is an experimentally determined value, while $[\text{Fe}^{3+}]$ can easily be computed from the expression:

$$K_{\text{Fe}(\text{SCN})^{2+}} = \frac{[\text{Fe}^{3+}][(\text{SCN})^{-}]}{[\text{Fe}(\text{SCN})^{2+}]} = 4 \cdot 10^{-3},$$

where

$$[\text{SCN}]^{-} = [\text{KSCN}] - [\text{Fe}(\text{SCN})^{2+}].$$

Substituting the equilibrium values of $[\text{Fe}^{3+}]$ and $[\text{FeF}^{2+}]$ in the expression

$$K_{\text{FeF}^{2+}} = \frac{[\text{Fe}^{3+}][\text{F}^{-}]}{[\text{FeF}^{2+}]} = 5 \cdot 10^{-6},$$

we can find the equilibrium concentration of fluoride ions, and from the expression

$$K_{\text{HF}} = \frac{[\text{H}^{+}][\text{F}^{-}]}{[\text{HF}]} = 1 \cdot 10^{-3},$$

where $[\text{H}^{+}] = 0.1$, we find $[\text{HF}]$, the equilibrium concentration of HF.

Substituting the values of $[\text{HF}]$, $[\text{F}^{-}]$ and $[\text{FeF}^{2+}]$ thus obtained in Equation (II), we can compute $[\text{AlF}^{2+}]$, and then, from the equation $[\text{Al}(\text{NO}_3)_3] = [\text{Al}^{3+}] + [\text{AlF}^{2+}]$, the equilibrium concentration of aluminum ions.

After these computations, we can solve expression (I) and find the value of the instability constant of AlF^{2+} .

The experimental determination of the concentration of $\text{Fe}(\text{SCN})^{2+}$ was carried out in each separate case by the method of comparing the optical densities of the solutions being investigated with the optical density of a solution containing a known concentration of $\text{Fe}(\text{SCN})^{2+}$ (comparison solutions).

See footnote previous page.

Table 2

Expt. No.	Comparison solutions	Solutions being investigated																
		T R A N S M I T T E D							C O M P U T E D									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	$[\text{Fe}(\text{SCN})^{2+}]$	Extinction (log I_0/I) of comparison sol	$[\text{Fe}(\text{NO}_3)_3]$	$[\text{KSCN}]$	$[\text{NaF}]$	$[\text{Al}(\text{NO}_3)_3]$	Extinction (log I_0/I) of comparison sol	Extinction of interest. Extinction of compar.	$[\text{Fe}(\text{SCN})^{2+}]$	$[(\text{SCN})^-]$	$[\text{Fe}^{3+}]$	$[\text{FeF}^{2+}]$	$[\text{F}^-]$	$[\text{HF}]$	$[\text{FeF}^{2+}] + [\text{F}^-] + [\text{HF}]$	$[\text{AlF}^{2+}]$	$[\text{Al}^{3+}]$	$K_{\text{AlF}^{2+}} \cdot 10^{-7}$
1	3.87	0.3032	20.4	97.5	20	20.4	0.2757	0.9093	3.52	93.98	14.98	1.90	0.634	6.33	8.29	11.71	8.69	4.7
2	3.87	0.3032	20.4	97.5	20	26.52	0.2823	0.9311	3.60	92.90	15.34	1.46	0.476	4.76	6.27	13.73	12.79	4.4
3	3.87	0.3032	20.4	97.5	20	36.72	0.2866	0.9462	3.66	93.84	15.60	1.14	0.395	3.65	4.83	15.17	21.55	5.2
4	4.09	0.3174	40.8	48.75	20	51	0.2800	0.9420	3.85	44.90	34.28	1.67	0.244	2.43	4.12	15.88	35.12	5.4
5	4.23	0.3080	20.6	107.6	100	306	0.2994	4.9670	4.09	103.51	15.81	0.7	0.22	2.2	2.92	97.08	208.92	4.7
6	6.54	0.4123	20.4	195	180	224.4	0.3516	0.8528	5.68	189.42	11.78	3.04	1.29	12.88	16.05	163.95	60.45	4.8
7	7.63	0.4413	61.2	64.56	20	10.2	0.3969	0.8994	6.86	57.70	47.56	6.78	0.713	7.12	13.97	6.03	4.17	4.9
8	7.84	0.3174	39.14	103	40	102	0.3080	0.9399	7.60	100.40	30.28	1.26	0.208	2.08	3.36	36.64	65.36	3.7
9	7.84	0.3179	39.14	108	40	204	0.3125	0.9830	7.71	100.29	30.75	0.68	0.11	1.1	1.79	38.21	165.79	4.8
10	8.08	0.4101	40.16	108.7	20	51	0.3968	0.9651	7.80	100.90	30.82	1.44	0.233	2.33	3.79	16.21	34.79	5.4
11	11.82	0.6383	61.2	107.6	28	20.4	0.5711	0.8347	10.58	97.02	43.62	7.00	0.902	8.01	15.09	12.91	7.49	4.7
12	11.82	0.6383	61.2	107.6	32	20.4	0.5691	0.8759	10.35	97.25	42.57	8.29	0.972	9.71	18.09	13.91	6.49	4.5
13	11.82	0.6383	61.2	107.8	36	20.4	0.5452	0.8541	10.10	97.50	41.44	8.66	1.17	11.69	21.36	14.64	5.76	4.6
Average																		
$4.8 \cdot 10^{-7}$																		

The comparison solutions, in contradistinction to the solutions under investigation, contained only $\text{Fe}(\text{NO}_3)_3$, KSCN , and HNO_3 (0.1 N), the concentrations of these salts (but not of $\text{Fe}(\text{SCN})^{2+}$) being the same in a given comparison solution and the solution under investigation.

The measurements of optical density were carried out, as they were carried out during the determination of the composition, from 26 to 30 hours after the mixing of the solutions.

All the data, experimental and computed, are listed in Table 2, the concentration there being given in hundred-thousandths (10^{-5}) of moles (or g-ions) per liter (except for the concentrations of fluoride ions, which are indicated in millionths (10^{-6}) of g-ions.)

In the last column of the table are given the values for the instability constant of the complex AlF_2^{2+} ions.

The average values from 13 experiments at different concentrations of the components reacting amounted, as can be seen from the tabulated data, to $4.8 \cdot 10^{-7}$.

If we estimate the accuracy of the determination of the $\text{Fe}(\text{SCN})^{2+}$ concentration as one or two units of the photocolormeter scale (including here not only the determination of the extinction of the solutions, but also all the errors in both experiment and computation) then we may accept for the instability constant of the complex alumino-monofluoride ions, AlF_2^{2+} , in aqueous solution a value of the order of $(4.8 \pm 0.2) \cdot 10^{-7}$.

This value is approximately one tenth the value of the instability constant of the iron-monofluoride complex ions:

$$K_{\text{FeF}_2^{2+}} = 5 \cdot 10^{-8}.$$

Therefore, the alumino-fluoride complexes are approximately 10 times as stable as the iron-fluoride complexes. This fact explains why the aluminum ions displace the ferric iron ions from double salts of iron with fluorine [1].

This difference in stability of aluminum and iron fluoride complexes is the basis for the method proposed by I.V. Tananaev and M.I. Levina for the determination of aluminum by means of the titration of sodium fluoride in the presence of ferric thiocyanate as an indicator [13]. During this process, the solution begins to be considerably decolorized, i.e., the iron thiocyanate complex begins to be transformed into a fluoride complex, only after the aluminum ions are all bound by the sodium fluoride.

Alumino-Fluoride Complexes with a Large Number of Coordinated Fluoride Ions

It is obvious that in solution, along with the AlF_2^{2+} complex ions of simple composition, there can exist more complicated ions as well. We may assume that in aluminum fluoride solutions, just as in solutions of ferric thiocyanate, ferric fluoride, and other complex compounds, the concentration of any given complex form (complex ions with larger or smaller numbers of addends) will depend on the concentration of the coordinated ions, in this case, of the fluoride ions.

Thus, I.V. Tananaev, as well as I.V. Tananaev and Yu.L. Lelchuk, have found that the saturation of the aluminum ions with fluoride ions takes place in a stepwise manner with the formation of the intermediate ions AlF_2^{2+} - AlF_2^{+} and undissociated AlF_3 [3], and as a result of this, a precipitate of $11\text{NaF} \cdot 4\text{AlF}_3$ is formed, while with an excess of NaF (1.4%), Na_3AlF_6 is formed [14].

The concentration of $\text{Fe}(\text{SCN})^{2+}$ in the comparison solutions could easily be computed from the expression:

$$K_{\text{Fe}(\text{SCN})^{2+}} = \frac{([\text{Fe}(\text{NO}_3)_3] - x)([\text{KSCN}] - x)}{x} = 4 \cdot 10^{-3}$$

where x is the concentration of $\text{Fe}(\text{SCN})^{2+}$.

** According to I. V. Tananayev and E. N. Deichmann, the composition of this salt is $5\text{NaF} \cdot 2\text{FeF}_3$ [12].

Thus, when the concentration of fluoride ions in solution is increased, there apparently must take place the formation, by steps, of more complex groups than AlF^{2+} - AlF_2^+ , AlF_3 , AlF_4^- , etc. The values of the instability constants of these groups can be computed as was indicated above, by using the coefficients of the relations between the values of pK ($= -\log K$), as derived by A.K. Babko [4].

These coefficients are as follows: $\text{pK}_2 = 0.84 \text{ pK}_1$, $\text{pK}_3 = 0.72 \text{ pK}_2$, $\text{pK}_4 = 0.56 \text{ pK}_3$, and $\text{pK}_5 = 0.2 \text{ pK}_4$. ($K_1 \dots K_5$ are the instability constants of the complex ions with one, two, etc. coordinated ions).

The values of the instability constants of the alumino-fluoride complex ions computed in this manner (the stepwise dissociation constants) are the following:

$$K_{\text{AlF}_2^+} = \frac{[\text{AlF}_2^+][\text{F}^-]}{[\text{AlF}_2^+]} = 4.9 \cdot 10^{-6}; \quad K_{\text{AlF}_2} = \frac{[\text{AlF}_2^+][\text{F}^-]}{[\text{AlF}_3]} = 1.5 \cdot 10^{-4};$$

$$K_{\text{AlF}_4^-} = 7.2 \cdot 10^{-3}; \quad K_{\text{AlF}_5^{2-}} = 0.37.$$

Starting from these values, we can obtain a picture of the relations between the concentrations of complex forms at different concentrations of fluoride ions in the solution.

The data of this computation are shown in Fig. 2 in the form of a diagram constructed according to the method of Michaelis. On the axis of abscissas are laid off the values of the negative logarithm of the concentration of fluoride ions ($-\log [\text{F}^-]$), and on the axis of ordinates the concentration of complex forms in percentages (total concentration of aluminum salts taken as equal to 100).

From the diagram it follows that the change in the concentration of one form or another during the change in the concentration of the fluoride ions is related to the change in the concentrations of the other complex forms which are mutually transformed into each other (AlF^{2+} into AlF_2^+ , etc.).

At the same time, if the concentration of fluoride ions is greater than 10^{-7} g-ions in one liter, there must exist together in the solution various forms of complex ions.

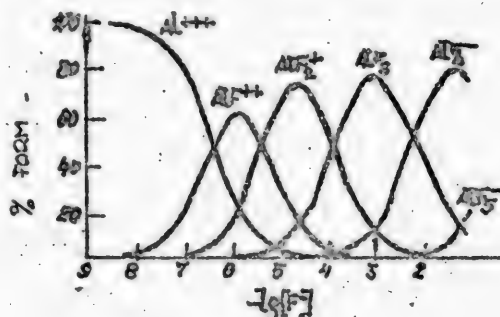


Fig. 2.

If we represent the dissociation of the AlF_5^{2-} complex by the equation $\text{AlF}_5^{2-} \rightleftharpoons \text{Al}^{3+} + 5\text{F}^-$, then the overall equilibrium constant is

$$K = \frac{[\text{Al}^{3+}][\text{F}^-]^5}{[\text{AlF}_5^{2-}]} = K_{\text{AlF}^{2+}} \cdot K_{\text{AlF}_2^+} \cdot K_{\text{AlF}_3} \cdot K_{\text{AlF}_4^-} \cdot K_{\text{AlF}_5^{2-}} = 0.94 \cdot 10^{-18}.$$

For purposes of orientation, in order to verify the correctness, even if only with regard to the order of magnitude, of the stepwise instability constants, we compared the value of the overall dissociation constant of the alumino-fluoride complexes (AlF_5^{2-} , AlF_4^- , etc.) with the value derived from the solubility of aluminum hydroxide, which is known.

For the equilibrium constant of the reaction $\text{AlF}_5^{2-} + 3\text{OH}^- \rightleftharpoons \text{Al}(\text{OH})_3 + 5\text{F}^-$ we have

$$K_{\text{equil.}} = \frac{[\text{F}^-]^5}{[\text{AlF}_5^{2-}][\text{OH}^-]^3}$$

or

$$K_{\text{equil.}} = \frac{[F^-]^5 [Al^{3+}]}{[AlF_5^{2-}]} \cdot \frac{1}{[Al^{3+}][OH^-]^3} = K'_{AlF_5^{2-}} \cdot \frac{1}{L_{pAl(OH)_3}},$$

where $K'_{AlF_5^{2-}}$ is the overall dissociation constant of AlF_5^{2-} (as distinguished from $K_{AlF_5^{2-}}$, the stepwise instability constant) and $L_{pAl(OH)_3}$ is the solubility product of aluminum hydroxide, which equals $4.7 \cdot 10^{-18}$ [15].

Consequently:

$$K_{\text{equil.}} = \frac{0.94 \cdot 10^{-18}}{4.7 \cdot 10^{-18}} = 0.2.$$

For the equilibrium constant of the reaction $AlF_4^- + 3OH^- \rightleftharpoons Al(OH)_3 + 4F^-$

we have

$$K_{\text{equil.}} = \frac{K'_{AlF_4^-}}{L_{pAl(OH)_3}} \cdot \frac{K_{AlF_2^+} \cdot K_{AlF_2^+} \cdot K_{AlF_3} \cdot K_{AlF_4^-}}{L_{pAl(OH)_3}} = \frac{2.54 \cdot 10^{-18}}{4.7 \cdot 10^{-18}} = 0.54.$$

and further



$$K_{\text{equil.}} = \frac{K'_{AlF_3}}{L_{pAl(OH)_3}} = 75;$$

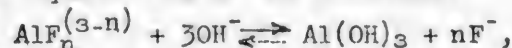


$$K_{\text{equil.}} = \frac{K'_{AlF_2^+}}{L_{pAl(OH)_3}} = 5 \cdot 10^5;$$



$$K_{\text{equil.}} = \frac{K'_{AlF^{2+}}}{L_{pAl(OH)_3}} = 1 \cdot 10^{11}.$$

Consequently, the equilibrium of the reactions:



for values of $n = 1, 2$, and 3 must be considerably shifted in the direction of formation of $Al(OH)_3$, and at higher values of n the reaction between the hydroxylated and the alumino-fluoride complex ions must be to a considerable degree suppressed.

This, of course, can take place when the concentration of the hydroxyl ions in solution is sufficient to attain the value of $L_{pAl(OH)_3}$ and provided the value of the stepwise dissociation constant of the alumino-fluoride complexes computed by us is close to the actual one.

In Table 3 are shown the experimentally observed changes in solutions containing $Al(NO_3)_3$ and NaF at different relative concentrations.

A series of mixtures was prepared, each containing 10 ml of 0.1 molar $Al(NO_3)_3$ solution ($M = 0.1079$) and different volumes of NaF solution ($M = 0.100$). The volume of each mixture was made up with water to 100 ml.

In solutions in which the molar ratio of NaF/ $Al(NO_3)_3$ was greater than 4, a finely crystalline precipitate was formed (at NaF/ $Al(NO_3)_3 = 5$, a slight cloudiness of $Al(OH)_3$ was also formed).

All the solutions were titrated with a solution of NaOH ($K = 0.079$), using phenolphthalein. Consequently, the $[OH^-]$ in all solutions was of the order of 10^{-6} g-ions per liter.

In column 4 of Table 3, there are noted the phase differences observed in

TABLE 3

Expt. No.	NaF Al(NO ₃) ₃	Volume (ml) of NaOH solution (K = 0.079) used in titration with phenolphthalein	Precipitate
1	Only Al(NO ₃) ₃	37.35	Al(OH) ₃ Volume of precipitate perceptibly decreased
2	1	30.1	
3	2	27.5	
4	3	25.3	
5	4	18.8	
6	5	12.4	Small amount amorphous precipitate
7	6	2.7	Crystalline precipitate and slight cloudiness
8	7	0.4	Crystalline precipitate
9	8	0.3	
10	9	0.3	

the solutions after titration with a solution of caustic soda.

The data of Table 3 in general confirm the computations we made above on the basis of the stepwise instability constants of the alumino-fluoride complexes, and thus, permit us to compute values fairly close to the actual values of these instability constants, and consequently, to give a general picture of complex formation in the system Al(NO₃)₃ - NaF - H₂O.

The closest to an analytical conclusion that can be drawn from all that has been said above is that in the presence of a considerable concentration of fluoride in solution, it is impossible to determine the concentration of aluminum by means of the precipitation of its hydroxide, and that it is impossible to determine the concentration of fluoride by means of the iron-thiocyanate reaction in the presence of salts of aluminum. The solution must first be free, in the one case of fluoride, and in the other of aluminum.

SUMMARY

1. The formation of alumino-fluoride complex groups has been investigated by means of the change in the intensity of the color of aqueous solutions, determined by the equilibrium:



2. It has been shown that at low concentrations of fluoride (of the order of 10^{-8} to 10^{-6} g-ions of fluoride per liter) in the solution, it is chiefly the complex cations of alumino-monofluoride (AlF²⁺) that are formed.

3. The dissociation constant of the complex alumino-monofluoride cations has been determined:

$$K_{\text{AlF}^{2+}} = \frac{[\text{Al}^{3+}][\text{F}^-]}{[\text{AlF}^{2+}]} = (4.8 \pm 0.2) \cdot 10^{-7}.$$

4. The aluminomonofluoride complex ions are approximately 10 times as stable as the iron-monofluoride ions ($K_{\text{FeF}^{2+}} = 5 \cdot 10^{-8}$).

5. On the basis of a picture of stepwise dissociation, more complicated forms of aluminofluoride complexes, $\text{AlF}_n^{(3-n)}$ (where $n = 2, 3, 4, 5$, or 6) must exist at higher concentrations of the fluoride ion. From the ratios of the stepwise dissociation constants, found by means of the electrostatic characteristics [4], we have computed the following dissociation constants:

$$K_{\text{AlF}_2^+} = \frac{[\text{AlF}_2^+][\text{F}^-]}{[\text{AlF}_2^+]} = 4.9 \cdot 10^{-8}; \quad K_{\text{AlF}_3} = \frac{[\text{AlF}_2^+][\text{F}^-]}{[\text{AlF}_3]} = 1.5 \cdot 10^{-4};$$

$$K_{\text{AlF}_4^-} = \frac{[\text{AlF}_3][\text{F}^-]}{[\text{AlF}_4^-]} = 7.2 \cdot 10^{-3}; \quad K_{\text{AlF}_5^{2-}} = \frac{[\text{AlF}_4^-][\text{F}^-]}{[\text{AlF}_5^{2-}]} = 0.37.$$

The product of five stepwise constants (the overall dissociation constant of AlF_5^{2-} , according to the equation AlF_5^{2-}) is:

$$K = K_{\text{AlF}^{2+}} \cdot K_{\text{AlF}_2^+} \cdot K_{\text{AlF}_3} \cdot K_{\text{AlF}_4^-} \cdot K_{\text{AlF}_5^{2-}} = 0.94 \cdot 10^{-18}.$$

6. A comparison of the computed values of the dissociation constants of the aluminofluoride complexes with the value of the "solubility product" of aluminum hydroxide ($\text{Lp}_{\text{Al}(\text{OH})_3}$), as well as with experimental data, has shown that the equilibria of the reactions $\text{AlF}_n^{(3-n)} + 3\text{OH}^- \rightleftharpoons \text{Al}(\text{OH})_3 + n\text{F}^-$ for values of $n = 1, 2$, and 3 must be shifted considerably in the direction of the formation of $\text{Al}(\text{OH})_3$, and that at higher values of n the reaction between the hydroxyl and the aluminofluoride complex ions must be to a considerable degree suppressed. Thus, for $n = 1$:

$$K_{\text{equil.}} = 1 \cdot 10^{11},$$

and for $n = 5$:

$$K_{\text{equil.}} = 0.2.$$

7. In order to analyze solutions which contain aluminum and fluoride at the same time, these solutions must first, in the different cases, be freed from fluoride (for the precipitation of aluminum hydroxide) or from aluminum (for the determination of the fluoride by means of the ferri-thiocyanate reaction).

LITERATURE CITED

- [1] Köhl, Beitz. zur analyt. Best. des Fluors. Diss. (1926) (Cited by I.V. Tananaev and M.I. Levina; cf. reference 13).
- [2] V.M. Tarayan, Factory Lab., XII, 6, 543 (1946).
- [3] I.V. Tananaev (Cited by reference 13).
- [4] A.K. Babko, J. Gen. Chem. 15, 745 (1945).
- [5] A.K. Babko, J. Gen. Chem. 16, 1549 (1946).
- [6] A.K. Babko and K.E. Kleiner, J. Gen. Chem. 17, 1259 (1947).
- [7] A.K. Babko, J. Gen. Chem. 15, 847 (1945).
- [8] A.K. Babko and E.K. Kleiner, J. Anal. Chem. 1, 2, 106 (1946).
- [9] P. Job, Ann. chim., 9, 113 (1928).
- [10] K.E. Kleiner, J. Gen. Chem. 20, 221 (1950).
- [11] F. Lindstrand, Über Eisenperchlorate (1939).
- [12] I.V. Tananaev and E.N. Deichman, Factory Lab., XI, 9, 763 (1945).
- [13] I.V. Tananaev and M.I. Levina, Factory Lab., XI, 9, 804 (1945).
- [14] I.V. Tananaev and Yu.L. Lelchuk, Proc. Acad. Sci. USSR, 3, 118 (1934).
- [15] N.A. Tananaev, Analytical Chemistry. State Sci-Tech Press of Ukrain, (1934).

Received January 4, 1949.

See CB translation p. 229 ff.

ON THE NATURE OF CRYSTALS

VI. THE INTERATOMIC LINKAGE OF ORGANIC CRYSTALS AND THE MUTUAL SOLUBILITY OF ORGANIC SUBSTANCES

V. Ya. Kurbatov

In a preceding paper, "The Interatomic Linkage of Metallic Crystals", it was shown that from the coefficients of expansion, density, and heat capacity it is possible to compute the value of the interatomic linkage of crystals, that is, of the force, expressed in atmospheres, opposing the thermal expansion of the crystal. In the case of metals it was shown that this value is in a simple ratio to the hardness according to Hertz-Brinel and to the melting point, i.e., that it is actually characteristic of the stability of the crystal.

The same value can be computed for a number of organic crystals; however, many of the data for the coefficient of expansion (especially those obtained by the students of Biltz) were measured at very low temperatures, and therefore are too high for the values of K_{cr} at temperatures which are of interest to industrial and laboratory workers. That is why these data were extrapolated to temperatures of 0 to 20°.

The values obtained are compared in Table 1. From them it is clear that the K_{cr} of typical organic crystals fluctuates within the very narrow limits of 10,000 to 20,000 atmospheres. Only for very high-melting crystals which are easily grown from the vapors (those which are sublimed), i.e., naphthalene and anthracene, does the value of K_{cr} exceed 20,000 atmospheres.

Although it is not very obvious, still it can be seen from the table that K_{cr} increases as we pass from substances with low ionizing ability (hydrocarbons, halogen derivatives) to substances with high ionizing ability (alcohols, acids). But the increase is not great (100%) because in pure form both alcohols and acids are very little ionized in comparison with their condition in alkaline medium.

If we compare the values of K_{cr} : m.p., it can be seen that they fluctuate within relatively narrow limits from 25 to 66, if we do not take into account the probably erroneous value for octyl alcohol (Table 2).

If we compare the values of K_{cr} , i.e., of the interatomic linkage of crystals, with K_l , the intermolecular linkage of the corresponding liquid, the first is of the same order as the second, but is approximately 1.5 times as great (Table 3).

Thus, as for typical organic liquids, the differences between the intermolecular linkages are in general not great, apparently the interatomic linkage of the crystals can differ appreciably only in the case of the higher cyclic hydrocarbons, which represent the transition to graphite with its gigantic value of K_{cr} (3,500,000 atmospheres).

At the same time, if we consider organic compounds with fairly long hydrocarbon

TABLE 1

The Interatomic Linkage of Organic Crystals

Name of substance.	C	d	$\beta = 3\alpha$	K_{cr}
Dodecane	0.44	0.795	0.03576	7100
Hexadecane	0.47	0.751	0.03962	9300
$C_{80}H_{122}$	0.48	0.9	0.0356	16000
Paraffin	0.475	0.86	0.0354	16000
Crude rubber	0.34	0.94	0.03657	12600
Benzene	0.315	0.879	0.0378	17800
Naphthalene	0.314	0.967	0.03283	22100
Anthracene	0.278	1.242	0.0322	35100
CH_2Br_2 (-100°)	0.114	2.488	0.0363	9900
CH_2I_2 (-97°)	0.0713	1.333	0.0349	10000
CH_3I_3	0.059	4.01	0.0348	17200
$CHBr_3$	0.094	2.89	0.0328	8300
CCl_4	0.177	1.594	0.0360	9700
CBr_4	0.083	3.42	0.0333	9600
Salol	0.25	1.2	0.03143	43000
Benzaldehyde	0.286	1.046	0.0334	12000
Camphor	0.309	0.811	0.03485	10800
Sucrose	0.304	1.588	0.0482	19300
Paraldehyde	0.381	0.994	0.0347	16600
Acetic anhydride	0.245	1.042	0.0349	9000
Dodecyl alcohol	0.459	0.84	0.0361	13000
Octyl alcohol	0.46	0.827	0.0341	19000
Phenol	0.304	1.060	0.0342	15900
Benzyl alcohol	0.324	1.045	0.0354	13000
Formic acid	0.313	1.22	0.0333	13500
Acetic acid	0.356	1.049	0.0356	14000
Propionic acid	0.368	0.922	0.0360	12500
Butyric acid	0.393	0.964	0.0367	12000
$C_7H_{15}CO_2H$	0.411	0.918	0.0347	12600
$C_8H_{19}CO_2H$	0.416	0.895	0.0372	11000
$C_{12}H_{24}O_2$	0.424	0.882	0.0340	12000
Palmitic acid	0.438	0.885	0.0345	17000
Stearic acid	0.44	0.941	0.0342	16000
Malonic acid	0.298	1.3	0.0318	14000
Benzoic acid	0.284	1.266	0.0320	15500
Salicylic acid	0.278	1.484	0.0338	22000
Urea	0.321	1.345	0.0357	16000
Cotton	0.411	1.51	0.0336	35000
Acetylcellulose	0.412	1.95	0.0344	28000
Viscose	0.420	1.49	0.0336	36000
Colophony	0.325	1.07	0.04637	113000
Bakelite	0.40	1.2	0.04630	100000
Celluloid	0.35	0.98	0.04570	110000
$K[CH_3COO]$	0.254	1.53	0.0360	13400
$K[C_{17}H_{35}COO]$	0.6	1.32	0.0352	31400
Oak wood	0.332	1.005	0.0315	45600

chains, the difference between their interatomic linkages is not too great.

Actually, hexane (petroleum ether) and heptane (gasoline) with K_1 close to 4500 atmospheres, go into solution in paraffin with K_{cr} of the order of 13000 atmos.; benzene with K_1 4500 goes into solution in naphthalene with K_{cr} of the

order of 22,000 atmos. Obviously, this process of solution takes place in a completely different manner from the solution of salts in water.

This fact was not taken into account by Hildebrandt in his book "The Solubility of Non-electrolytes" (there is a Russian translation) and therefore he could compare the solubility only of hydrocarbons with high melting points (anthracene, diphenylmethane, and naphthalene). In this connection, an entire series of pairs of organic liquids is known which give eutectics at fairly low temperatures, and therefore we must consider not the value of the solubility at some arbitrarily chosen temperature, but the course of the curves of crystallization from the solution.

Moreover, it was shown long ago (V. Kurbatov, 1924) that it is necessary to distinguish between three kinds of processes of solution.

a) Intermolecular, when the dissolving particles are dispersed between the particles of the solvent. Strictly speaking, we can refer here only to the mutual solubility of gases at not too great pressure, where the dimensions of the molecules are small in comparison with the spaces between them. Therefore: 1) all vapors and gases are completely soluble in each other; 2) all the properties of these solutions are additive (Dalton's law of the addition of partial pressures). Intermolecular solution is also possible, although at extremely low concentrations, in the case of liquids (for example, C_8H_{18} in water 0.001%) and in crystals (for example, Na_n in NaCl with the appearance of a blue color.

b) Isofluid and isomorphic types of solution, i.e., the substitution of particles, atoms, or groups of atoms of one substance by the particles, atoms, or groups of atoms of the other substance, when the substances are sufficiently alike chemically and crystallographically. The idea of "similarity" had not been thoroughly defined, but:

1) For isomorphism, the more complicated the overall molecular composition, the less similarity is required in properties and composition. For example, Na^+ and K^+ are isomorphous in the micas, but not in the feldspars (perthites). Apparently, there is a limit to the extent of substitution of K^+ by Na^+ , but the possibility is not excluded that $Na[Al(SO_4)_2] \cdot 12H_2O$ and $K[Al(SO_4)_2] \cdot 12H_2O$, although they are isomorphous with each other with regard to the analysis of the entire mass, do not in fact form a microeutectic. NaCl and KCl, NaOH and KOH at high temperatures (i.e., somewhat lower than the melting point) are isomorphous, but at considerably lower

TABLE 2

The Interatomic Linkage and Melting Points of Organic Crystals

Name of substance	K_{cr}	M.p.	$K_{cr}:M.p.$
$C_{60}H_{122}$	16000	473	33.5
Benzene	7300	279	26.1
Naphthalene	22000	353	61
Anthracene	33000	490	69
CH_2Br_2	9900	25	39
CH_2I_2	10000	279	35
$CHBr_3$	8300	281	30
CHI_3	11200	392	24
CCl_4	9700	250	39
CBr_4	9600	367	26
Benzaldehyde	12000	247	48
Camphor	10800	453	25
Paraldehyde	16600	261	64
Acetic anhydride.	9000	250	36
Octyl alcohol ...	19000	258	73
Dodecyl alcohol..	13000	301	43
Phenol	16000	314	51
Benzyl alcohol ..	13000	255	50
Formic acid	13500	281	49
Acetic acid	14000	290	48
Propionic acid ..	12500	265	48
Butyric acid	12000	251	48
$C_7H_{17}COOH$	13000	289	47
$C_{10}H_{19}COOH$	11000	304	36
$C_{12}H_{23}COOH$	12000	317	38
Palmitic acid ...	17000	335	53
Stearic acid	16000	342	47
Malonic acid	14000	409	36
Benzoic acid	14000	315	50
Salicylic acid ..	22000	428	51

temperatures break up into a eutectic.

2) In the crystalline condition, that is, with oriented positions of the ions (or atoms) the degree of similarity required is considerably higher than in the liquid state. Therefore substances which are isomorphous are always isofluid, but the reverse law is very seldom true.

3) Above all else, similarity is required in regard to chemical properties, and therefore all homologs of a given series are soluble in each other.

4) The closer to each other two liquids stand in the series of arrangement of liquids according to intermolecular linkage (V.Kurbatov, 1917-1927), the more probable is their mutual solubility.

c) The coordination-solvate-ionic type of solution, characteristic of electrolytes in water, is based on the formation by the solvent of a coordination-constructed aqueous shell of ions, which in its turn, by the exchange of H^+ OH^- ions, is attracted into the water solvent. This type of solution has been fairly completely reviewed previously.

Let us turn to the isofluid type of solution of liquids, characteristic for

TABLE 3

A Comparison of the Intermolecular Linkage of Liquids K_l with the Interatomic Linkage of Crystals, K_{cr}

Substance	K_{cr}	K_l	$K_{cr}:K_l$
Benzene	7300	4600	1.4
Naphthalene...	22000	(9000)	2.4
$C_2H_2Br_2$	9000	6000	1.5
$CHBr_3$	8300	7200	1.2
CCl_4	9700	5100	1.9
Camphor	11000	(10000)	1.1
Octyl alcohol.	19000	(10000)	1.9
Phenol	16000	(10000)	1.6
Formic acid ..	13500	13400	1.1
Acetic acid...	14000	10000	1.4

TABLE 4

The Solubility of Naphthalene (20°)

Solvent	Interatomic linkage	Solubility (Mol %)
Hexane.....	4200	12.1
CCl_4	5000	25.7
Benzene ...	4700	29.2
Toluene....	5700	28.9
C_6H_5Cl ...	6800	31.3
$C_6H_5NO_2$...	10200	29.5
$C_6H_5NH_2$...	9000	17.2
C_2H_5OH	10000	2.4

organic liquids. We may say beforehand, with complete assurance, that decane and diisooctyl, for example,

which are very similar in the structure of their molecules, with almost equal intermolecular linkages, cannot help mixing with each other if these liquids come in contact. Therefore it is impossible to pour two layers of these together in such a manner as not to mix them. Moreover, the similarity of the molecules of saturated hydrocarbons is so great that they are all soluble in each other, and consequently even the derivatives of these hydrocarbons are completely soluble in them if the paraffin chain of the derivatives is sufficiently long. The chief difference between the liquids is the degree of difference of ionic interchange between their micromolecules, and second comes the degree of difference between their intermolecular linkages, which depends primarily on the degree of ionic interchange between the micromolecules.

For example, triphenylmethane, whose intermolecular linkage is close to that of anthracene (we assume it is of the order of 50,000 atmos.) is not completely soluble in hydrocarbons.

Solubility of triphenylmethane at 20°

In hexane	benzene	carbon disulfide	chloroform
30 mol %	32.4 mol %	19.1 mol %	25.8 mol %

Because of its three phenyl groups it is closer to benzene than to hexane, and its solubility in the latter is appreciably lower (Table 4).

It is clear that isofluidism depends less on the ratio between the values of the intermolecular linkages than on the degree of chemical similarity. Actually, if decane and diisooamyl were selected above as examples of chemical closeness, then decane and water are examples of extreme difference. Let us assume that by means of an extremely powerful ultrasonic generator we had produced an almost molecular dispersion of decane in water. As soon as the action of the generator ceased, the differences between the properties of decane and water, and especially their intermolecular linkages (decane about 7,000, water about 75,000) would be so great that the micromolecules of water formed by the ionic interchange of the macromolecules with each other would inevitably "repel" from them the molecules of decane, which, as the easiest course, would form an upper layer. In order that decane dissolve in water in appreciable amount, it is necessary for its molecules to acquire ionic properties, a result which can be most easily attained by the introduction of an OH or COOH group. In fact, while C_6H_{14} is almost insoluble in water, $C_6H_8(OH)_8$ is excellent soluble; while ethylene is weakly soluble in water, succinic acid $C_2H_4(COOH)_2$ is soluble in water, etc.

During the past decade, industry has placed upon the market a whole series of solvents, both those which have a very complicated structure (for example, epiethylene, $CH_2 \begin{array}{c} \diagup \diagdown \\ O \end{array} CH \cdot CO_2OC_2H_5$) and those with a very simple structure, like the

amines of the saturated series. They have met the demands of the automobile industry for the preparation of nitrocellulose lacquers, because these latter must have both the property of drying fairly rapidly, but not too rapidly, and of transforming into colloid solution such complicated compounds, or more probably mixtures of compounds, as the nitrocelluloses. We may note first of all that the interatomic linkage of cellulose derivatives must be high. Suppose we ask: how is this in accord with the possibility of dissolving these substances in liquids which have comparatively simple molecules, for example, in acetone, and why are cellulose derivatives sometimes insoluble in pure liquids, such as alcohol and ether separately, but soluble in a mixture of them?

The first question, obviously, is like the question of why crystals of naphthalene with an interatomic linkage of 22000 atmos. dissolve in benzene, which has an interatomic linkage of 6700 atmos? The ionic properties of naphthalene are somewhat higher than those of benzene. However, they are not very great, and there is no considerable lack of correspondence between C_6H_6 and $C_{10}H_8$. That is why the molecules of benzene, with their kinetic energy absorb the molecules of naphthalene in their place. Although the benzene molecules themselves cannot enter into the naphthalene lattice, the interaction, at the place of rupture from the crystal, of a particle of naphthalene with two molecules of benzene, is not so very different from the interaction between the rest of the naphthalene crystal and the molecule of $C_{10}H_8$ torn away from it.

Thus, there is no doubt that the solution of naphthalene in benzene takes place according to the isofluid type. However, they are not isomorphous in the crystalline condition, i.e., in other words, the introduction of benzene into liquid naphthalene lowers the temperature of crystallization of the latter, and vice versa.

In the case of the nitrocelluloses and other cellulose ethers, the following fundamental relations are observed:

- a) An increase in the degree of etherification increases the solubility up to a definite limit;
- b) considerably nitrated cellulose is soluble in acetone;

- c) considerably acetylated cellulose acetate is soluble in acetic acid, phenol, and a mixture of CCl_4 and $\text{C}_2\text{H}_5\text{OH}$;
- d) less considerably acetylated cellulose is soluble in acetone;
- e) the ethyl ethers of cellulose are soluble even in cyclic hydrocarbons;
- f) the transition from ethers of cellulose with residues of a higher degree of ionogenic ability (nitro) to average (acetyl) and lower (ethyl) degrees corresponds to the transition from a solvent of a higher degree of ion formation to a solvent of a lower degree of ion formation. (For a more detailed comparison, see: V. Kurbatov. Processes of Solution of Cellulose Derivatives. Collection, "Plastics" 1936).

From these comparisons it follows directly that the solution of cellulose ethers, which have a high K_{Cr} , is essentially isofluid. However, not the molecules, but more or less disintegrated crystallopolyions of the cellulose ethers dissolve colloiddally, as these ethers have a very complicated structure. Consequently, the solvent too must have a fairly complicated structure. In fact, in the cellulose ethers, we have:

- a) Hydrocarbon chains or rings, very weakly ionic, corresponding to the weakly ionic $(\text{C}_2\text{H}_5)_2\text{O}$ and CCl_4 , and also to the tautomeric forms of acetone, acetic acid, etc.;
- b) weakly ionic groups, such as the hydroxyls of alcohol, acetic acid, the enol form of acetone;
- c) there may be more powerful, strongly ionic groups like NO_3 , and
- d) Ca^{++} , Na^+ , PO_4^{---} ions, which were present in the original cellulose and are partially retained after treatment.

In order to go over into solution (for c and d) water is needed in its ionic form, and for a and b in its nonionic form.

It is clear that, in the first place, for the solution of ether derivatives of cellulose, despite their "insolubility" in water, some water, even though a very small amount of it, is needed in the solvent. This is also confirmed experimentally. In the second place, it is necessary that the solvent contain at the same time molecules of weakly ionic and molecules of relatively strongly ionic character. In the third place, it is necessary that the ratios between the three types of solvent molecules, that is, 1) the almost nonionic, 2) the weakly ionic, 3) the ionic, be such that during the motions of the crystallo-polyions (more exactly, of their fragments) of the cellulose ethers, in the vast majority of cases, the ratios between the three forms of molecules as statistically calculated should not surpass the limits of allowable fluctuations for the corresponding ratios between the particles of different ionic tendency in a given type of cellulose ether.

Experiment shows that actually, the higher the ionogenic properties of the group that is introduced into the cellulose, the higher must be the ionic tendency of the solvent. At the same time it is necessary that the solvent consist of more ionic molecules (enolic in the case of acetone, ionic $\text{H}[\text{C}_2\text{H}_3\text{O}_2]$ in the case of acetic acid) and less ionic molecules (ketonic in the case of acetone and nonionic in the case of acetic acid), or that it consist of a mixture of two substances, one more ionic (like alcohol) and the other less ionic (like ether).

Thus, the solution of cellulose ethers is isofluid, in contrast to what is usually thought, and in contrast to the solution of cellulose itself in ammoniacal copper solution or in thiocarbamic ester, where complex compounds are formed with substances which enter into the solvent. However, in view of the complexity of structure of the crystallo-polyions or of the fragments of these crystallo-polyions, it is impossible to carry out the solution in a single solvent which has tautomeric forms close to each other. That is why for cellulose ethers a mixture of solvents

is needed, whose composition, however, is made still more complicated both to decrease the speed of evaporation of the very volatile solvent to a sufficient extent, and because it is necessary to add "plasticizers" to the lacquer, that is, substances which will prevent too great hardening of the lacquer. These questions have no relation to the fundamental question we have chosen, because the fundamental task was the determination of the values and the ratio between the values of the interatomic linkage of organic crystals.

The closeness of the computed values of K_{cr} for organic crystals of different homologous types to each other explains the mutual solubility of the majority of organic substances in each other, and at the same time permits us to conclude that:

- 1) The solution of organic substances in each other takes place according to the isofluid type;
- 2) The colloid solution of cellulose ethers takes place according to the isofluid type; however, because of the numerous differences between the particles of cellulose ether crystallo-polyions, it is necessary that the solvent contain molecules of at least three types: a) strongly ionic (water), b) appreciably ionic (the enol forms of ketones, ionic forms of acids), c) weakly ionic (the keto forms of ketones, ethers, hydrocarbons, nonionic forms of acids).

SUMMARY

1. Values of the interatomic linkage of organic crystals, computed according to the formula suggested by V. Kurbatov (1940) fluctuate within the very narrow limits of 7,000 to 20,000 atmospheres.
2. Cellulose and its ethers has K_{cr} considerably higher (of the order of 30,000 to 35,000 atmospheres).
3. The ratio between K_{cr} and the m.p. fluctuates from 25 to 70, that is, within narrow limits.
4. K_{cr} for crystals of a given substance is appreciably higher than the K_l of the corresponding liquid.
5. The solution of organic liquids in each other takes place according to the isofluid type.
6. The use of mixed solvents for cellulose ethers is dependent upon the fact that solution takes place according to the isofluid type, while it is necessary that the solvent consist of molecules of different degrees of ion-forming ability in proportion to the different ion-forming abilities of the various particles of crystallo-polyions of the cellulose ethers.

Received November 16, 1948.

MUTUAL SOLUBILITY IN THE SYSTEM $\text{H}_3\text{BO}_3\text{-KNO}_3\text{-H}_2\text{O}$

Ya. Ugay and T. Simkina

Department of General and Inorganic Chemistry of the Voronezh State University

At present, the question of the complex treatment of potassium borates to give potassium and magnesium salts and boric acid is an important one. If we consider the nitric acid method of decomposing boron-containing minerals, we shall find in the mother liquid, first of all, boric acid, potassium nitrate, and magnesium nitrate. Hence, it becomes necessary to investigate the conditions of polythermal crystallization and the disintegration of the phases (H_3BO_3 , KNO_3 , $\text{Mg}(\text{NO}_3)_2$, H_2O) after the neutralization of the mother liquid. Therefore, we undertook the investigation of equilibrium in the quaternary system $\text{H}_3\text{BO}_3\text{-KNO}_3\text{-Mg}(\text{NO}_3)_2\text{-H}_2\text{O}$. The physico-chemical data we obtained will serve as a basis for correctly carrying out the process of crystallizing out the substances in the production of boric acid and potassium and magnesium nitrates.

In this work, we present the results of an investigation of the ternary system $\text{H}_3\text{BO}_3\text{-KNO}_3\text{-H}_2\text{O}$, which is a component part of the quaternary system mentioned above, and has a peculiar significance.

The work was carried out by the visual-polythermal method of Alekseeva and Bergman [1,2].

The binary systems $\text{H}_3\text{BO}_3\text{-H}_2\text{O}$ and $\text{KNO}_3\text{-H}_2\text{O}$ are simple and have two branches of crystallization each. In these systems, no crystal hydrates are formed. The data of different authors on the solubility of boric acid are in comparatively good agreement with each other, and they were taken by us from Landolt's tables [3,4]. The cryohydrate point corresponds to a temperature of -0.8° and to 2.3% of boric acid.

As for the binary system $\text{KNO}_3\text{-H}_2\text{O}$, we examined this chiefly during the course of investigation of the ternary system itself, with regard to the original section points, the sections beginning on the side $\text{KNO}_3\text{-H}_2\text{O}$. In Table 1 are listed our numerical data, in which, in addition to the original section points, are listed various supplementary investigations of the composition of the system $\text{KNO}_3\text{-H}_2\text{O}$.

Our data agree satisfactorily with the data of other authors [6,7,8,9,10,11,12,13,14] who have investigated the solubility of potassium nitrate in water. The eutectic point is characterized by a temperature of -2.7° and a potassium nitrate content of 10.2%.

In order to investigate the ternary system properly, we studied 8 internal sections of which 6 started with solution of KNO_3 and water and 2 sections started with solutions of boric acid (Fig. 1). The equilibrium curves of all the sections consist of two branches, which intersect at a single transition point (Figs. 2 and 3). The experimental data on the sections is listed in Table 2. They permit us to draw up a picture of the behavior of boric acid and potassium nitrate in aqueous solution. All percentages by weight.

solution when they are both present, and to sketch the fields of crystallization of the components of the system.

The results of the investigation of the internal sections combined with the binary systems made it possible to construct an equilibrium diagram for the system $\text{H}_3\text{BO}_3 - \text{KNO}_3 - \text{H}_2\text{O}$ (Fig. 1). On the diagram, constructed by the first method of Roozboom, are given the isotherms from 5 to 25° for each 5°, and in the field of crystallization of ice there are shown in addition the isotherms for -1° and -2°.

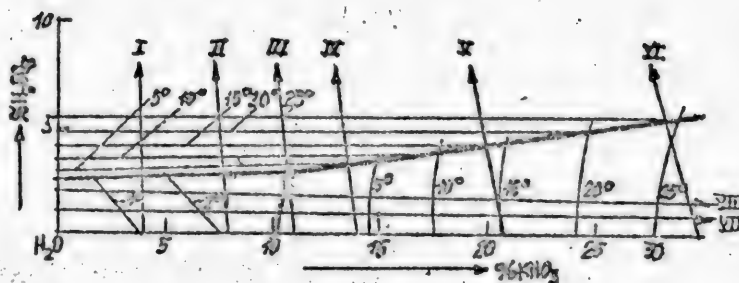


Fig. 1.

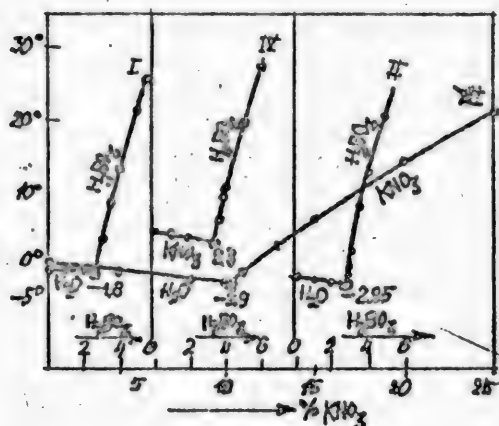


Fig. 2.

TABLE 1

The System $\text{KNO}_3 - \text{H}_2\text{O}$

Expt. No.	KNO_3 , %	Temperature °C	Solid phase
1	4.0	-1.1	H ₂ O
2	8.0	-2.1	
3	9.5	-2.5	
4	11.0	-0.8	KNO ₃
5	14.0	+4.2	
6	17.7	10.0	
7	21.0	15.4	
8	25.0	21.2	
9	30.0	27.5	

The isothermal selections for 0, 5, 10, 15, 20, and 25° are listed in Table 3. These data were obtained by interpolation by transferring the corresponding isothermal points from the diagrams of the sections and binary systems.

As can be seen from the diagram (Fig. 1), the ternary system $\text{H}_3\text{BO}_3 - \text{KNO}_3 - \text{H}_2\text{O}$, in the temperature interval from complete solidification to +25° forms only 3 fields of crystallization of the original components. This indicates that no chemical compound is formed between the substances under investigation in aqueous solution. Neither are any solid solutions formed, nor hydrates, nor products of metathesis.

The ternary eutectic corresponds to the temperature -3.2° and the composition 2.9% H_3BO_3 , 10.75% KNO_3 , and 86.35% H_2O .

The character of the isotherms in the domain of crystallization of boric acid indicates the increase of its solubility in the presence of potassium nitrate ("salting in" effect). It is very obvious that during this process a decrease of the activity coefficient of H_3BO_3 takes place as the concentration of the KNO_3 increases. We decided to trace the course of the change of the activity coefficient of boric acid at different temperatures when a saturated solution of potassium nitrate was added to it.

TABLE 2

Expt. No.	Added substance, %	Temperature, °C	Solid phase	Expt. No.	Added substance, %	Temperature, °C	Solid phase
1	2	3	4	1	2	3	4
Section I (4% KNO ₃ + 96% H ₂ O) → H ₃ BO ₃				Section II (8% KNO ₃ + 92% H ₂ O) → H ₃ BO ₃			
1	0.0	-1.1	ice	1	0.0	-2.1	ice
2	1.0	-1.3		2	1.0	-2.35	
3	2.0	-1.6		3	2.0	-2.65	
4	2.5	-1.75		4	2.5	-2.75	
5*	2.7	-1.8	ice + H ₃ BO ₃	5*	2.8	-2.85	ice + H ₃ BO ₃
6	2.8	+0.8	H ₃ BO ₃	6	3.0	+1.9	H ₃ BO ₃
7	3.0	-3.6		7	3.5	7.7	
8	3.5	8.5		8	4.0	12.3	
9	4.0	12.7		9	5.0	20.4	
10	5.0	21.2					
Section III (11% KNO ₃ + 89% H ₂ O) → H ₃ BO ₃				Section IV (14% KNO ₃ + 86% H ₂ O) → H ₃ BO ₃			
1	0.0	-0.8	KNO ₃	1	0.0	4.2	KNO ₃
2	1.0	-1.4		2	1.0	3.8	
3	2.0	-2.2		3	2.0	3.5	
4	2.5	-2.8		4	3.0	3.0	
5*	2.7	-3.1	KNO ₃ + H ₃ BO ₃	5*	3.3	2.8	KNO ₃ + H ₃ BO ₃
6	3.0	+1.1	H ₃ BO ₃	6	3.6	6.1	H ₃ BO ₃
7	3.5	6.9		7	4.0	10.4	
8	4.0	11.8		8	5.0	19.4	
9	5.0	18.8		9	6.0	27.4	
10	6.0	24.5					
Section V (21% KNO ₃ + 79% H ₂ O) → H ₃ BO ₃				Section VI (30% KNO ₃ + 70% H ₂ O) → H ₃ BO ₃			
1	0.0	15.4	KNO ₃	1	0.0	27.5	KNO ₃
2	1.5	15.1		2	2.0	26.6	
3	3.0	14.7		3	4.0	25.6	
4	4.0	14.4		4*	5.5	24.6	
5*	4.2	14.35	KNO ₃ + H ₃ BO ₃	5	6.0	28.8	H ₃ BO ₃
6	4.5	16.5	H ₃ BO ₃	6	7.0	34.9	
7	5.0	20.0					
8	6.0	26.6					
Section VII (1% H ₃ BO ₃ + 99% H ₂ O) → KNO ₃				Section VIII (2% H ₃ BO ₃ + 98% H ₂ O) → KNO ₃			
1	0.0	-0.3	ice	1	0.0	-0.7	ice
2	4.0	-1.4		2	4.0	-1.6	
3	8.0	-2.4		3	8.0	-2.6	
4	10.0	-2.8		4	10.0	-3.0	
5*	10.3	-2.9	H ₂ O + KNO ₃	5*	10.5	-3.1	H ₂ O + KNO ₃
6	11	-1.5	KNO ₃	6	11.0	-1.9	KNO ₃
7	13	+2.5		7	13.0	+2.2	
8	15	6.0		8	15.0	6.1	
9	20	14.2		9	20.0	14.1	
10	25	21.0		10	25.0	20.9	

* Points obtained graphically.

* Points obtained graphically.

TABLE 3
Isotherms of the System $\text{H}_3\text{BO}_3\text{-KNO}_3\text{-H}_2\text{O}$

Expt. No.	Number of section	Weight percent			Per 100 g of dry substance		Water, g per 100 g dry substance	Solid phase
		H ₂ O	KNO ₃	H ₃ BO ₃	KNO ₃	H ₃ BO ₃		
1	2	3	4	5	6	7	8	9
0° Isotherm								
1	Binary	97.6	0.0	2.4	0.0	100.0	4066.0	H ₃ BO ₃
2	1	93.41	3.89	2.7	59.02	40.98	1417.0	
3	2	89.33	7.77	2.9	72.82	27.18	837.1	
4	3	86.33	10.67	3.0	78.05	21.95	631.6	
5	-	85.00	11.90	3.1	79.44	20.66	566.6	H ₃ BO ₃ + KNO ₃
6	8	86.34	11.9	1.76	87.12	12.88	632.2	KNO ₃
7	7	87.42	11.7	0.88	93.01	6.99	694.8	
8	Binary	88.5	11.5	0.0	100.0	0.0	769.5	
5° Isotherm								
1	Binary	97.1	0.0	2.9	0.0	100.0	3348.0	H ₃ BO ₃
2	1	93.02	3.88	3.1	55.58	44.42	1332.0	
3	2	89.06	7.44	3.2	70.73	29.27	813.9	
4	3	86.02	10.63	3.35	76.00	24.00	615.1	
5	4	82.99	13.51	3.5	79.43	20.57	488.1	H ₃ BO ₃ + KNO ₃
6	-	81.9	14.6	3.5	81.00	19.00	444.6	
7	8	83.89	14.4	1.71	89.39	10.61	520.7	KNO ₃
8	7	84.74	14.4	0.86	94.39	5.61	555.4	
9	Binary	85.5	14.5	0.0	100.0	0.0	589.6	
10° Isotherm								
1	Binary	96.50	0.0	3.50	0.0	100.0	2757.0	H ₃ BO ₃
2	1	92.50	3.85	3.65	51.34	48.66	1233.0	
3	2	88.55	7.70	3.75	67.25	32.75	773.2	
4	3	85.62	10.58	3.80	73.57	26.43	595.5	
5	4	82.65	13.45	3.9	77.51	22.49	476.3	H ₃ BO ₃ + KNO ₃
6	-	78.60	17.50	3.90	81.77	18.23	367.3	
7	8	80.95	17.40	1.65	91.33	8.67	424.9	KNO ₃
8	7	81.67	17.50	0.83	95.45	4.55	445.9	
9	Binary	82.3	17.7	0.0	100.0	0.0	464.6	
15° Isotherm								
1	Binary	95.90	0.0	4.1	0.0	100.0	2339.0	H ₃ BO ₃
2	1	91.97	3.83	4.20	47.70	52.30	1145.0	
3	2	87.95	7.70	4.35	63.90	36.10	729.8	
4	3	85.10	10.50	4.40	70.47	29.53	571.1	
5	4	82.22	13.38	4.40	75.25	24.75	462.4	H ₃ BO ₃ + KNO ₃
6	5	75.52	20.08	4.40	82.02	17.98	308.5	
7	-	75.05	20.6	4.35	82.56	17.44	300.8	KNO ₃
8	8	77.81	20.6	1.59	92.85	7.15	350.8	
9	7	78.61	20.6	0.79	96.31	3.69	367.6	
10	Binary	79.30	20.7	0.0	100.0	0.0	383.1	

TABLE 3 (Continued)

Expt. No.	Number of section	Weight percent			Per 100 g of dry substance		Water, g per 100 g dry substance	Solid phase
		H ₂ O	KNO ₃	H ₃ BO ₃	KNO ₃	H ₃ BO ₃		
20° Isotherm								
1	Binary	95.25	0.0	4.75	0.0	100.0	2004.0	H ₃ BO ₃
2	1	91.34	3.81	4.85	45.02	54.98	1080.0	
3	2	87.45	7.60	4.95	60.48	39.52	695.2	
4	3	84.60	10.40	5.00	67.53	32.47	549.4	
5	4	81.70	13.30	5.00	72.68	27.32	446.4	
6	5	75.05	19.95	5.00	79.96	20.04	300.8	
7	—	70.50	24.55	4.95	83.22	16.78	239.0	H ₃ BO ₃ + KNO ₃
8	8	74.19	24.3	1.52	94.14	5.86	287.4	KNO ₃
9	7	75.04	24.2	0.76	96.96	3.04	300.6	
10	Binary	75.8	24.2	0.0	100.0	0.0	313.2	
25° Isotherm								
1	Binary	94.55	0.0	5.45	0.0	100.0	1735.0	H ₃ BO ₃
2	1	90.53	3.77	5.70	39.80	60.20	955.9	
3	2	86.65	7.60	5.75	56.93	43.07	657.4	
4	3	83.90	10.35	5.75	64.37	35.63	546.2	
5	4	81.10	13.20	5.70	69.84	30.16	429.0	
6	5	74.50	19.80	5.70	77.64	22.36	292.2	
7	6	66.08	28.32	5.60	83.49	16.51	194.9	H ₃ BO ₃ + KNO ₃
8	—	65.80	28.60	5.60	83.62	16.38	192.4	
9	8	70.66	27.9	1.44	95.98	4.02	240.8	KNO ₃
10	7	71.48	27.8	0.72	97.48	2.52	250.7	
11	Binary	72.3	27.7	0.0	100.0	0.0	261.0	

Using the expression

$$\underline{a} = m_0 \gamma_0 = m_1 \gamma_1 = m_2 \gamma_2 = \dots = \text{const.},$$

where \underline{a} is the activity of the saturated solution of H_3BO_3 ; \underline{m}_0 is the molarity of boric acid in pure water; $\underline{m}_1, \underline{m}_2 \dots$ are the molarities in the presence of different amounts of KNO_3 ; and $\gamma_0, \gamma_1, \gamma_2 \dots$ are the corresponding activity coefficients of H_3BO_3 in these solutions, we first determined the value of \underline{a} . For this purpose we constructed a graph showing the relationship of $1/\underline{m}$ to $\sqrt{\mu}$ (Fig. 4), where μ is the total ionic strength of the solution. In computing μ we took into account only the first stages of the dissociation of boric acid.

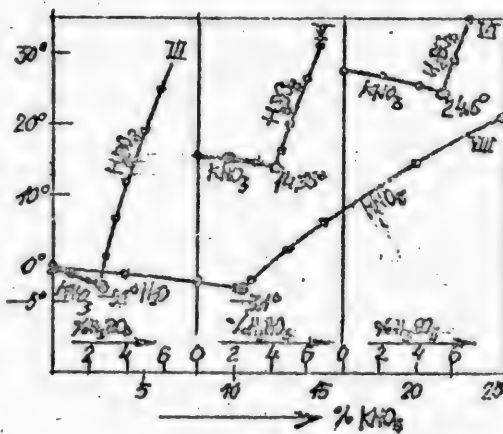


Fig. 3.

By extrapolating the series of values of $1/m$ against $\sqrt{\mu}$ (infinite dilution of the solution) we obtain $\underline{m} = \underline{a}$, as during this $\mu = 1$. After finding \underline{a} , it is easy to obtain from the expression given above the value of μ for every \underline{m} . These data are summarized in Table 4, and in Figs. 4 and 5.

TABLE 4

The System $\text{H}_3\text{BO}_3 - \text{KNO}_3 - \text{H}_2\text{O}$

Expt. No.	Composition of solution %			Composition of solution in moles per 1000 g H ₂ O			$\frac{1}{m}$	$\sqrt{\mu}$	λ H ₃ BO ₃
	KNO ₃	H ₃ BO ₃	Σ	KNO ₃	H ₃ BO ₃	Σ			
Temperature 0°									
1	0.0	2.4	2.4	0.0	0.398	0.398	—	—	0.8890
2	3.89	2.7	6.59	0.412	0.468	0.880	2.139	0.938	0.7508
3	7.77	2.9	10.67	0.860	0.525	1.385	1.905	1.179	0.6686
4	10.67	3.0	13.67	1.223	0.559	1.782	1.790	1.338	0.6247
Temperature 10°									
1	0.0	3.5	3.5	0.0	0.587	0.587	—	—	0.8525
2	3.85	3.65	7.50	0.412	0.638	1.050	1.567	1.025	0.7836
3	7.70	3.75	11.45	0.860	0.685	1.545	1.460	1.245	0.7302
4	10.58	3.80	14.38	1.223	0.718	1.941	1.393	1.393	0.6968
5	13.45	3.90	17.35	1.610	0.763	2.373	1.311	1.540	0.6654
Temperature 20°									
1	0.0	4.75	4.75	0.0	0.807	0.807	—	—	0.8052
2	3.81	4.85	8.66	0.412	0.858	1.270	1.165	1.127	0.7565
3	7.60	4.95	12.55	0.860	0.916	1.776	1.092	1.261	0.7094
4	10.40	5.00	15.40	1.216	0.955	2.171	1.047	1.473	0.6795
5	13.30	5.00	18.30	1.611	0.990	2.601	1.010	1.613	0.6561

Table 4 and Fig. 5 obviously indicate the character of the change in the activity coefficient of boric acid as the concentration of KNO_3 in the solution increases. The greatest decrease in the activity coefficient is observed at 0°. A rise in temperature results in a less sharp decrease of the activity coefficient of H_3BO_3 , i.e., the "salting in" ability of the KNO_3 is greater at lower temperature.

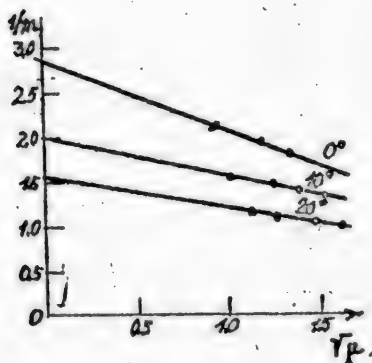


Fig. 4.

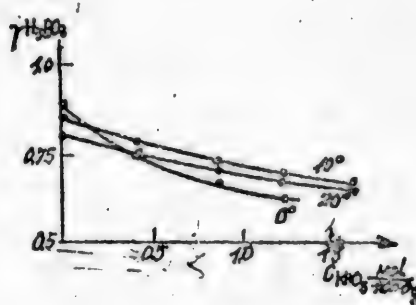


Fig. 5.

SUMMARY

1. Using the polythermal visual method of Alekseeva and Bergman, we have investigated the equilibria in the system $\text{H}_3\text{BO}_3 - \text{KNO}_3 - \text{H}_2\text{O}$ from the temperature of the ternary eutectic up to +25°.

2. The investigation of the ternary system is an integral part (the face of the tetrahedron of compositions) of the quaternary system $H_3BO_3 - KNO_3 - Mg(NO_3)_2 - H_2O$, which is being investigated in connection with the attempt to find the physico-chemical foundations for the production of boric acid and potassium and magnesium nitrates.

3. In the system $H_3BO_3 - KNO_3 - H_2O$, there is no formation of chemical compounds, nor of solid solutions, nor of products of metathesis.

4. The equilibrium domains of crystallization of the original components, boric acid, potassium nitrate, and water, meet at a single ternary eutectic point, observed at the temperature of -3.2° , and the composition of 2.9% H_3BO_3 , 10.75% KNO_3 , and 86.35% H_2O .

5. It has been noted that potassium nitrate has a "salting in" effect with regard to boric acid; this is related to the decrease of the activity coefficient of H_3BO_3 in KNO_3 solutions.

6. The activity coefficients of saturated solutions of boric acid have been computed for the temperatures of 0, 10, and 20° , in the presence of various amounts of potassium nitrate in the solution.

LITERATURE CITED

- [1] A. Bergman, Trans. June Session Acad. Sci. USSR, II, 167-180 (1932).
- [2] A. Belopolsky and Urusov, J. Appl. Chem. 21, 8 (1948).
- [3] Landolt, Tabellen, Ed. I, 653 (1923).
- [4] Ibid, Ed. 2, 349 (1931).
- [5] Ibid, Ed. 3, 496 (1935).
- [6] de Coppet, Z. phys. Chem. 22, 239 (1897).
- [7] K. Wright, J. Chem. Soc., 1334 (1927).
- [8] W. Nikolajew, Z. allgem. anorg. chem., 182, 249 (1929).
- [9] S. Gladston and H. Saunders, J. Am. Chem. Soc., 123, 2134 (1923).
- [10] W. Ehret, J. Am. Chem. Soc., 54, 3133 (1932).
- [11] J. Ricci, *ibid.*, 56, 303 (1934).
- [12] H. Benrath and H. Wazelle, Z. allgem. anorg. Chem., 184, 360 (1929).
- [13] A. Rakovsky and D. Slavina, Trans. Inst. Sect. Chem. of Reagent, No. 11, 20-23 (1931).
- [14] A. Bergman and P. Bochkarev, Bull. Acad. Sci. USSR, Chem. Ser., I, 237 (1938).
- [15] V. Anosova and S. Pogodin, Foundations of Phys Chem. Anal., 541 (1947).

January 23, 1949.

THE RELATIONSHIP BETWEEN THE AMOUNT OF CATION ADSORBED AND THE WEIGHT OF ADSORBENT

A. T. Davidov and I. Ya. Levitsky

The A. M. Gorky Kharkov State University

In an investigation of the phenomenon of ion interchange on different adsorbents it is customary to take into account three types of functional relationship, namely: the relationship of the amount of adsorption to the volume, the concentration, and the weight of sample of adsorbent.

Considerably fewer papers have been devoted to the last type, that is, the relationship of the amount of cation adsorbed to the weight of sample of adsorbent, than to the second, that is, the relationship of the amount of cation adsorbed to the concentration.

Both the second and the third cases of relationship of the amount of adsorbed ions are of great practical significance with regard to the construction and use of filters for removing salts from water. In the present work we shall consider the applicability of the equations for the isotherms of exchange adsorption given by Gapon [1] for a similar case. The method of investigation of cation exchange on glauconite* has been given in the work of one of the present authors, [2].

In considering the theory of the relationship of the amount of cations adsorbed to the volume of displacing agent, Gapon arrived at the conclusion that with an increase in the volume of solution of the displacing cation at constant concentration, the amount of cation adsorbed and the amount of cation desorbed must increase.

We did not regard the case of adsorption investigated by the author of the equation as independent, but considered another formulation of the question: a series of constant weights of adsorbent with different volumes of solution is the same as a series of changed weights of adsorbent with constant volume of solution.

From what has been said above it follows that the equation given can also be applied to the case considered by us in the present work. In its general form, it is:

$$\frac{\left(\frac{fG_0}{v}\right)^{\frac{1}{m}}}{\left(C_0 - \frac{fG_0}{nv}\right)^{\frac{1}{n}}} \cdot \frac{fG_0}{G_{\infty} - fG_0} = K, \quad (1)$$

where: G_{∞} is the capacity for adsorption, calculated per 1 g of adsorbent;

G_0 is the amount of adsorbed cation for the actual volume of solution;

v is the volume of solution per 1 g of adsorbent;

g is the weight of adsorbent (in g);

*The present work was carried out on enriched glauconite of the Saratov region.

G is the amount adsorbed, expressed as a function of G_0 ; $G = fG_0$, where f is a coefficient of proportionality;

K is constant;

m and n are the valences of the cations to be exchanged.

Carrying out the transformation, and recalculating equation (1) for our case, we obtain the equation in this form:

$$\frac{g}{G} = \frac{1}{G_{\infty}} + \frac{1}{KG_{\infty}} \cdot \frac{\left(\frac{G}{v_m}\right)^{\frac{1}{m}}}{\left(C_0 - \frac{G}{v_n}\right)^{\frac{1}{n}}} \quad (2)$$

Thus, by plotting on a curve

$$y = \frac{g}{G}, \quad x = \frac{\left(\frac{G}{v_m}\right)^{\frac{1}{m}}}{\left(C_0 - \frac{G}{v_n}\right)^{\frac{1}{n}}},$$

we should obtain the isotherm in the form of a straight line, under conditions in which K is constant (the value of y at $x = 0$ will be designated by y_0).

Let us proceed to a consideration of the experimental data obtained by us. These are given in Tables 1, 2, 3, 4, 5, and 6 below:

TABLE 1
 $Ca^{++} + Na^{+}$

g	G	v(cc)	m	C_0	n	$\frac{g}{G}$	x	K	
2	0.410	100	2	0.1 N	1	4.87	0.00770	463	$y_0 = 1.3$ $K_{av} = 468$
4	0.675	100	2	0.1	1	5.90	0.00990	467	
6	0.900	100	2	0.1	1	6.60	0.0115	460	
8	1.103	100	2	0.1	1	7.30	0.125	480	
10	1.293	100	2	0.1	1	7.75	0.0138	467	
12	1.463	100	2	0.1	1	8.22	0.0146	473	

TABLE 2
 $Ca^{++} + K^{+}$

g	G	v(cc)	m	C_0	n	$\frac{g}{G}$	x	K	
2	0.570	100	2	0.1 N	1	3.50	0.007171	305	$y_0 = 1.3$ $K_{av} = 312$
4	0.952	100	2	0.1	1	4.20	0.009273	312	
6	1.300	100	2	0.1	1	4.61	0.01084	306	
8	1.575	100	2	0.1	1	5.07	0.01198	316	
10	1.850	100	2	0.1	1	5.40	0.01294	317	
12	2.105	100	2	0.1	1	5.70	0.01380	318	

TABLE 3
Sr⁺⁺ + Na⁺

g	G	v(cc)	m	Co	n	$\frac{g}{G}$	x	K	
2	0.315	100	2	0.1 <u>N</u>	1	6.34	0.00678	520	y ₀ = 2.8 K _{av} = 528
4	0.533	100	2	0.1	1	7.50	0.008833	534	
6	0.727	100	2	0.1	1	8.25	0.01032	529	
8	0.899	100	2	0.1	1	8.89	0.01147	529	
10	1.071	100	2	0.1	1	9.33	0.01253	522	
12	1.220	100	2	0.1	1	9.83	0.01337	524	

TABLE 4
Sr⁺⁺ + K⁺

g	G	v(cc)	m	Co	n	$\frac{g}{G}$	x	K	
2	0.425	100	2	0.1 <u>N</u>	1	4.70	0.006192	435	y ₀ = 2.0 K _{av} = 426
4	0.731	100	2	0.1	1	5.47	0.008124	428	
6	0.991	100	2	0.1	1	6.05	0.009461	430	
8	1.246	100	2	0.1	1	6.50	0.01062	424	
10	1.458	100	2	0.1	1	6.85	0.01149	421	
12	1.678	100	2	0.1	1	7.15	0.01232	418	

TABLE 5
Ba⁺⁺ + Na⁺

g	G	v(cc)	m	Co	n	$\frac{g}{G}$	x	K	
2	0.295	100	2	0.1 <u>N</u>	1	6.77	0.007568	876	y ₀ = 0.2 K _{av} = 921
4	0.503	100	2	0.1	1	7.95	0.00858	901	
6	0.652	100	2	0.1	1	9.20	0.009695	917	
8	0.784	100	2	0.1	1	10.20	0.01071	934	
10	0.900	100	2	0.1	1	11.11	0.01149	948	
12	0.938	100	2	0.1	1	12.79	0.01315	953	

TABLE 6

g	G	v(cc)	m	Co	n	$\frac{g}{G}$	x	K	
2	0.421	100	2	0.1 <u>N</u>	1	4.75	0.006162	233	y ₀ = 3.3 K _{av} = 246
4	0.752	100	2	0.1	1	5.33	0.008239	247	
6	1.060	100	2	0.1	1	5.66	0.009786	240	
8	1.322	100	2	0.1	1	6.05	0.01094	252	
10	1.586	100	2	0.1	1	6.30	0.001197	250	
12	1.837	100	2	0.1	1	6.53	0.11289	258	

SUMMARY

1. It has been shown that Gapon's equation can be satisfactorily applied to the case of the relationship of the amount adsorbed to the weight of the adsorbent.
2. It has been shown that the increase in the amount of adsorption of the cation takes place more slowly than the increase in the weight of adsorbent.

3. The isotherms obtained for adsorption exchange have a straight-line character in all cases.

4. The value of the constant very satisfactorily confirms the constancy of the relationship considered.

LITERATURE CITED

[1] E.N.Gapon, J.Gen.Chem. 3, no. 6, p. 662 (1933).

[2] A.T.Davidov and R.Z.Gurevich, Trans. Inst. Chem. Kharkov State Univ., 6, 62 (1946).

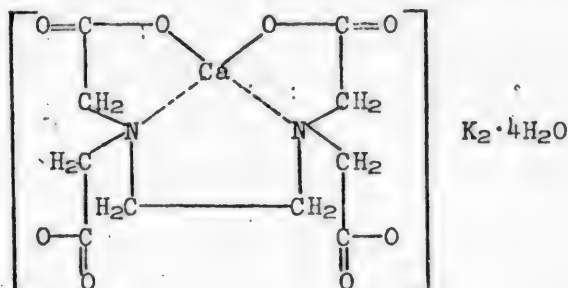
Received May 10, 1948.

ON CERTAIN INTERNAL-COMPLEX COMPOUNDS OF THE ELEMENTS OF GROUP II AND THEIR SOLUBILITIES

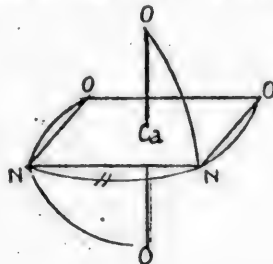
K. V. Astakhov and E. D. Kiseleva

1. Introduction

During the past years we have acquired a wide acquaintanceship with internal-complex (chelate) compounds, - derivatives of iminodiacetic acid $R-N(CH_2COOH)_2$, nitrilotriacetic acid $N(CH_2COOH)_3$, and ethylenediaminetetraacetic acid (ethylene-bis-iminodiacetic acid) $(HOOCCH_2)_2N-CH_2-CH_2-N(CH_2COOH)_2$ [1]. The tetra sodium salt of the latter is recommended by some firms [2] under the name of "Verzen" as one of the best means of softening water. In the patent literature, the tetra-sodium (or disodium) salt of ethylenediaminetetraacetic acid has been given the name of "Trilon B", and the sodium salt of nitrilotriacetic acid the name "Trilon A". Pfeiffer and Offermann [3] have prepared calcium and copper salts of Trilon A and Trilon B. With regard to the calcium derivative of ethylenediaminetetraacetic acid (Trilon B), its potassium salt has been considered, with good reason, to have a formula characteristic of internally-complex compounds, with a five-membered ring, and coordination bonds:



An analogous structure has been ascribed to the magnesium salt as well. In later work by Pfeiffer and Simons [4,5], the calcium, strontium, and barium salts have been described. For these salts, the authors suggest a spatial octahedral structure; for example, the calcium salt is supposed to have the following kind of structure.



The arc which is marked twice signifies an ethylene bridge, and the four unmarked arcs are four CH_2CO residues. As can be seen from the sketch, the atom of alkaline earth metal is surrounded by four atoms of oxygen and two atoms of nitrogen. The suggested structure for the calcium salt finds confirmation in the directed valences of the nitrogen atoms, but at the same time there is some difficulty in explaining it from the electron point of view if we represent a coordination bond as a donor-acceptor bond and the Ca^{++} ion as an acceptor of electrons. However, no matter how we represent the structure of the internal-complex compounds of the alkaline earth metals, the very fact of their existence is of considerable significance, and has remarkable interest. In the work of Pfeiffer and Simons [4,5], they suggested the formula $\text{Na}_2[\text{CaC}_{10}\text{H}_{12}\text{O}_8\text{N}_2] \cdot 6\text{H}_2\text{O}$ for the hydrate of the sodium salt of calcium-ethylenediaminetetracetic acid, thus indicating the presence of 6 molecules of water in the molecule of crystal hydrate. Noting the formation by the salts of alkaline earth metals of internal-complex compounds with the sodium salt of ethylenediaminetetracetic acid, the authors cited stress the considerable solubility of these internal-complex compounds in water or in alkaline solutions. In fact, the carbonates of calcium, strontium, and barium easily dissolve in a solution containing soda and the sodium salt of ethylenediaminetetracetic acid. The same ready solubility in alkaline solutions of this salt is observed for the carbonate and sulfate of lead and so on. At the same time we must note that the stability of the solutions obtained by dissolving the carbonates of calcium, strontium, or barium in alkaline solutions of the sodium salt of ethylenediaminetetracetic acid is not retained upon acidification. First the carbonate precipitates from the solution, and with an appreciable amount of added acid, there precipitates ethylenediaminetetracetic acid, which is comparatively little soluble in water. However, the very fact of the solution of the carbonates of the alkaline earth metals in alkaline solutions is of extraordinary interest not only scientifically, because of the formation of internal-complex compounds, but from the practical point of view as well, as it indicates the possibility, for example, of removing calcium salts which are insoluble in water without using acid solutions for this purpose.

In connection with what has been said, we can understand why the tetrasodium salt of ethylenediaminetetracetic acid has been used under the name "Trilon B" or "Verzen" as a softener of natural water. The interest which the internal-complex compounds have aroused in general, and the rare case of their formation by alkaline earth metals, induced us to begin a series of investigations devoted to the internal-complex compounds of calcium, strontium, barium, cadmium, and zinc, under the assumption that such investigations would permit us to broaden the range of practical application of Trilon B to the field of the physiology of living organisms as well. Preliminary experiments showed the formation of colored compounds of Trilon B with salts of trivalent chromium, cobalt, boron, etc., and therefore it was not without interest to investigate its applicability to analytical chemistry as well. However, in the present work, we have limited our task only to an experimental investigation devoted to the preparation of internal-complex compounds of the elements of Group II with Trilon B and to a study of the solubilities of the sodium salts of derivatives of Trilon B and alkaline earth metals.

2. The Preparation and Analysis of Internal-Complex Compounds of Trilon B* and Salts of Metals of Group II

In order to investigate the solubility of the internal-complex compounds of Trilon B with the salts of metals of group II of the periodic system, the compounds

*An investigation of the applicability of Trilon B for the solution of problems in analytical chemistry is successfully being carried out by S. S. Ivlev.

**Here and further on, the disodium salt of ethylenediaminetetracetic acid will sometimes be called, for the sake of brevity, Trilon B, and sometimes the disodium salt of ethylene-bis-iminodiacetic acid.

were synthesized, repeatedly recrystallized, and subjected to analysis. The prepared commercial product, Trilon B, was recrystallized, for the purpose of purification, from aqueous alcohol solutions.

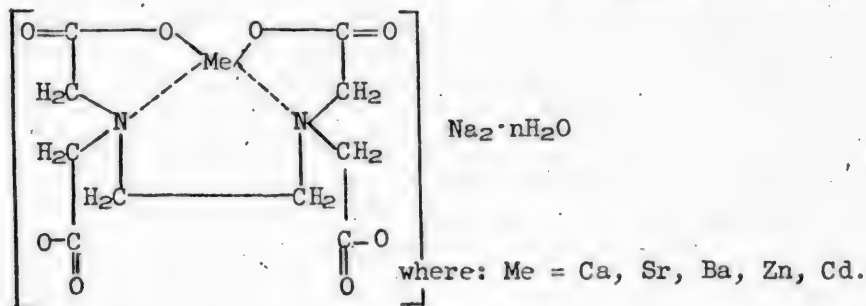
The preparation of the calcium, strontium, barium, cadmium, and zinc derivatives was carried out by one and the same method. To an aqueous suspension of Trilon B (4.4 g) there was gradually added a 0.02 N solution of sodium hydroxide until the salt had completely dissolved, as was indicated by the disappearance of the cloudiness of the solution. Into the transparent solution obtained, a dry powder of the carbonate was sprinkled (in the case of the preparation of the zinc compound, a powder of zinc oxide was used). The solution was boiled for 40 to 50 minutes in the presence of the solid carbonate, and was then filtered while hot through a glass filter. The transparent filtrate was evaporated on the water bath until a liquid of syrupy consistency formed. Upon cooling, methyl alcohol was added to the liquid. After comparatively lengthy standing, with frequent, discontinuous, vigorous shaking, fine white crystals of the internal-complex compound precipitated from the liquid. The crystals were separated by filtration, washed with a mixture of water and alcohol, with alcohol, and finally with ether, and dried in a desiccator at a temperature from 50 to 80°.

All the compounds obtained were very soluble in water, very slightly soluble in alcohol, and practically insoluble in ether and in benzene. The aqueous solutions of the salts gave an alkaline reaction to litmus. The addition of a solution of ammonium oxalate to the solutions of internal-complex compounds of the metals of Group II we had obtained did not result in the formation of a precipitate. A precipitate formed immediately when the mixture was acidified.

For the purpose of analysis, the salts obtained were recrystallized several times from aqueous methyl alcohol. Carbon and hydrogen were determined by combustion according to Friedrich's method (microdetermination). The water of crystallization was determined by the hydride method of A.G. Elitsur [6], with the use of pyridine as a dehydrating medium.

Thus, we prepared in pure form, and subjected to analysis, the sodium salts of calcium ethylenediaminetetracetic, strontium ethylenediaminetetracetic, barium ethylenediaminetetracetic, zinc ethylenediaminetetracetic, and cadmium ethylenediaminetetracetic acids.

To all the compounds obtained we had to ascribe the following structural formula:*



Here the coordination bonds are shown by dotted lines. Inasmuch as this article does not have the object of determining the space formula, not all the possible coordination bonds have been noted in the given structural formula. Although we did not have the intention of considering the compounds we had obtained from the electronic point of view, we consider it formally possible, for the sake of simplicity and ease of perception, to separate the coordination bonds (although only a few of them) without entering into the details of their nature. The proposed structural formulas are largely unconfirmed by direct experiment, and can be regarded as very probable, correctly describing the properties of the compounds obtained.

1. The sodium salt of calcium ethylenediaminetetracetic acid



According to the analytical data, the sample of the compound tested had 15.8% of water of crystallization, while the theoretical content was 15.5%.

0.0266 g substance: 0.0251 g CO_2 ; 0.0112 g H_2O .

0.0232 g substance: 0.0218 g CO_2 ; 0.0092 g H_2O .

Found %: C 25.8, 25.7; H 4.42, 4.41.

$\text{Na}_2[\text{CaN}_2\text{C}_{10}\text{H}_{12}\text{O}_8] \cdot 4\text{H}_2\text{O}$. Computed %: C 26.0; H 4.43.

It is necessary to note that in the work of Pfeiffer and Simons [4] cited above, experimental data are given, according to which this sodium salt crystallizes in the form of a hexahydrate., $\text{Na}_2[\text{CaN}_2\text{C}_{10}\text{H}_{12}\text{O}_8] \cdot 6\text{H}_2\text{O}$. Having no reason to distrust the data given in the work by Pfeiffer and Simons, and being convinced of the accuracy of our own investigations, we are inclined to accept the possibility that both crystal hydrates exist. We may make the assumption that the difference in the content of water of crystallization is the result of lack of uniformity in the conditions of crystallization and of the drying of the crystal hydrates obtained by us and described in the work of Pfeiffer and Simons.

2. The sodium salt of strontium ethylenediaminetetracetic acid



According to the analytical data, the sample of salt tested contained 18% of water of crystallization, while the theoretical content was 17.6%.

0.0360 g substance: 0.0295 g CO_2 ; 0.0138 g H_2O .

0.0272 g substance: 0.0224 g CO_2 ; 0.0102 g H_2O .

Found %: C 22.5, 22.5; H 4.25, 4.13.

$\text{Na}_2[\text{SrN}_2\text{C}_{10}\text{H}_{12}\text{O}_8] \cdot 5\text{H}_2\text{O}$. Computed %: C 22.6; H 4.15.

3. The sodium salt of barium ethylenediaminetetracetic acid



According to the analytical data, the sample of salt tested had 20.5% of water of crystallization; the theoretical content was 20.2%.

0.0264 g substance: 0.0168 g CO_2 ; 0.0112 g H_2O .

0.0282 g substance: 0.0202 g CO_2 ; 0.0119 g H_2O .

Found %: C 19.4, 19.5; H 4.7, 4.7.

$\text{Na}_2[\text{BaN}_2\text{C}_{10}\text{H}_{12}\text{O}_8] \cdot 8\text{H}_2\text{O}$. Computed %: C 20.1; H 4.7.

4. The sodium salt of cadmium ethylenediaminetetracetic acid



According to the analytical data, in two samples that were tested there was found 13.6 and 13.7% respectively of water of crystallization; the theoretical amount is 13.6%. In this compound, in addition to a quantitative determination of the carbon and hydrogen content, the content of cadmium was determined by the sulfate method. A sample of the substance was oxidized with sodium peroxide; then, after a preliminary treatment of the oxidation product with acetic acid, cadmium sulfide was precipitated with hydrogen sulfide. The cadmium sulfide was transformed into the sulfate by means of concentrated sulfuric acid, and the latter was roasted to constant weight.

0.6810 g substance: 0.2774 g CdSO_4 .

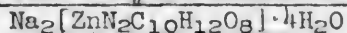
0.6870 g substance: 0.2783 g CdSO_4 .

0.0362 g substance: 0.0306 g CO_2 ; 0.0126 g H_2O .

Found %: Cd 21.7, 21.8; C 23.04; H 3.85.

$\text{Na}_2[\text{CdN}_2\text{C}_{10}\text{H}_{12}\text{O}_8] \cdot 4\text{H}_2\text{O}$. Computed %: Cd 21.7; C 23.2; H 3.78

5. The sodium salt of zinc ethylenediaminetetraacetic acid



According to the analytical data, the sample of salt tested had 15.6% of water of crystallization; the theoretical amount was 15.3%. In this compound, in addition to a quantitative determination of the carbon and hydrogen content, the content of zinc was also determined. A sample of the substance was oxidized with sodium peroxide; the residue from the oxidation was acidified with acetic acid and treated with hydrogen sulfide. After the zinc sulfide had been separated, it was converted into zinc oxide.

0.6138 g substance: 0.1010 g ZnO.

0.6751 g substance: 0.1122 g ZnO.

0.0262 g substance: 0.0241 g CO₂; 0.0098 g H₂O.

0.0284 g substance: 0.0262 g CO₂; 0.0107 g H₂O.

Found %: Zn 13.2, 13.3; C 25.2, 25.1; H 4.15, 4.2.

Na₂[ZnN₂C₁₀H₁₂O₈] · 4H₂O. Computed %: Zn 13.7; C 25.4; H 4.25.

III. The Solubility of the Sodium Salts of Calcium, Strontium, and Barium Ethylene-bis-iminodiacetic Acids

As already mentioned above, the carbonates of the alkaline earths which are very slightly soluble in water are very soluble in an alkaline solution (pH > 7) of the sodium salt of ethylene-bis-iminodiacetic acid (Trilon B). The process of solution is accompanied by the formation of an internal-complex salt. The finding of the numerical value of the solubility was accomplished by preparing saturated solutions of the compounds named above and determining the concentrations of calcium, strontium, and barium in the saturated solutions. The corresponding compounds were placed in small test tubes, fitted with stirrers and closed with stoppers; the compounds were first carefully purified by several recrystallizations, and the test tubes were rinsed out twice with doubly distilled water. The test tubes were heated on the boiling water bath until the compounds placed in them completely dissolved. The test tubes were then placed in a thermostat at 30 ± 0.1°, where they remained until no more crystallization took place. Samples of the transparent solutions were removed with pipettes, and the content of alkaline earth metals in them was determined. Similar analyses were carried out several times. On the basis of the values of the concentration obtained, the solubilities were computed in grams of anhydrous salt per liter.

1. The calcium salt. In 20 ml of saturated solution, 0.0082 g of calcium was found, corresponding to 37.4 g/liter. Thus, the solution of the calcium salt saturated at 30° is 0.1 molar.

2. The strontium salt. In 2 ml of saturated solution, 0.01717 g of strontium was found, corresponding to 41.3 g/liter. Thus, the solution of the strontium salt saturated at 30° is 0.098 molar.

3. The barium salt. In 2 ml of saturated solution, 0.0472 g of barium was found, corresponding to 81 g/liter. Thus, the solution of the barium salt saturated at 30° was 0.17 molar.

A comparison of the solubility data of the sodium salts of the calcium, strontium, and barium ethylene-bis-iminodiacetic acids made it possible to draw the conclusion that the molar concentrations of their saturated solutions were very close to each other, becoming slightly higher for the barium salt. The slight increase in the solubility of the barium salt is doubtless related to the fact that its crystal hydrate contains considerably more water of crystallization. If we keep in mind the fact that the solubility determinations were carried out for internal-complex salts, in which the atoms of the alkaline earth metals were

in the inner sphere, we shall be able to understand the lack of dependency of their solubility on the atomic weight of the complex-former.

CONCLUSIONS

1. The sodium salts of calcium, strontium, and barium ethylene-bis-iminodiacetic acids have been prepared in pure form, and the sodium salts of zinc and cadmium ethylene-bis-iminodiacetic acid (ethylenediaminetetracetic acids) have been prepared for the first time.

2. The composition and the amount of water of crystallization have been found in the crystal hydrates of these compounds.

3. The solubility at 30° has been determined for the sodium salts of calcium, strontium, and barium ethylene-bis-iminodiacetic acids.

4. The comparatively great solubility of the derivatives of Trilon B and the salts of the alkaline earth metals permits us to accept the possibility of their utilization in chemical analysis and in many branches of technology and physiology.

5. The interest which the preparation of these compounds has aroused has induced us to consider it expedient to investigate the stability constants of these compounds, and thus to determine the concentrations of ions of the alkaline earth metals in their aqueous solutions.

6. The formation of colored compounds of Trilon B with salts of chromium, cobalt, iron, etc., with different colors depending on the valence of the atom of cobalt, and so on, as well as the different solubilities of the internal-complex compounds, gives us ground for investigating the applicability of Trilon B in solving various questions of analytical chemistry.

LITERATURE CITED

- [1] Schwarzenbach G., Schweiz. Chem. Ztg., 22, 376 (1946).
- [2] Chem. Eng. News, 26, 2171 (1948).
- [3] Pfeiffer, Offermann, Ber., 75, 1 (1942).
- [4] Pfeiffer, Simons, Ber., 76, 847 (1943); C.A., 38, 2931
- [5] P. Pfeiffer, Ber., 77 A, 59 (1944).
- [6] A.G.Elitsur, J.Gen.Chem. 14, 923 (1944); J. Appl. Chem., 14, 682 (1941); Factory Lab., 12, 794 (1946); J. Platinum Dept., Inst. Gen. and Inorg. Chem., Acad. Sci. USSR, No. 22, 149 (1947).

Received January 4, 1949.

ON THE CHEMISTRY OF THE PROCESSES OF DECOLORIZATION OF DYES WITH SILVER

III. THE REDUCTION OF AZO DYES WITH SILVER IN A SOLUTION OF SODIUM SULFIDE

G. I. Arbuzov* and L. I. Gilman*

All-Union Scientific-Research Kino-Photo Institute

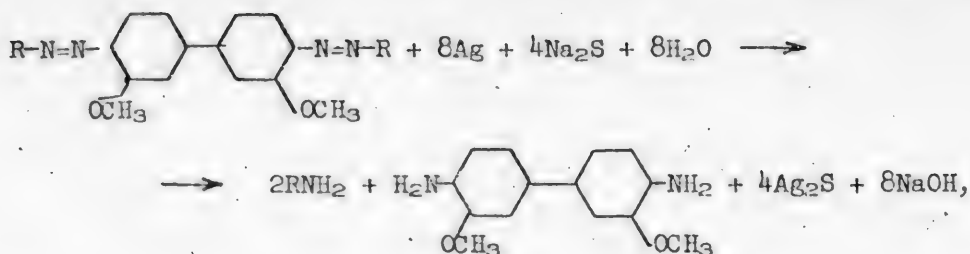
One of the methods of obtaining colored images is based on the decolorization of uniformly colored gelatin layers in the portions which contain photographically developed metallic silver.

Previously, one of the authors [1] explained the chemistry of the processes of decolorization of dyes by treatment of the colored gelatin layers containing photographic images with dilute hydrogen halide acids (HBr) or solutions of thiourea, acidified with hydrochloric or sulfuric acid. It was shown that during this sort of treatment, the reduction of the azo dye by the silver of the photographic image takes place, as a result of which, the color disappears from those portions which contain developed metallic silver. This process of decolorization of the dyes takes place to some degree in proportion to the densities of the silver image and leads to the formation of colored images. At the same time, in the case of treatment with hydrogen halide acids, the silver is converted into silver halide, while by treatment with acid solutions of thiourea the silver is converted into the corresponding complex salts with thiourea.

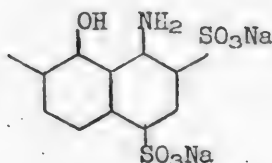
In one of the patents [2] it is claimed that to decolorize dyes it is possible to use other organic and inorganic sulfur-containing compounds as well, including sodium sulfide, calcium polysulfide, etc. It is asserted in the patent, however, that upon treatment of the colored layers containing silver images with a solution of sodium sulfide, the decolorization of the dye takes place only upon the addition to the solution of methyl-p-aminophenol or other reducing agents. We tested this method, and found that upon treating the colored gelatinous layers containing photographic images with a 1.8% solution of sodium sulfide, the effect of decolorization took place for an entire series of azo dyes (Acid Blue, Direct Red CC, Direct Pure Blue, etc.), while, contrary to the indications of the patent, decolorization of the dyes took place even without the addition of methyl-p-aminophenol. This process takes place fairly rapidly, and in the course of a few minutes the dye is completely decolorized in the places of greatest density of the silver image. After the silver had been removed by converting it, by the action of copper chloride, into silver chloride, and dissolving the latter in thiosulfate, in addition to the colored image (inverted) formed by the dye, there remained a silver sulfide image (direct) which was removed from the layer by treatment with a concentrated solution of potassium cyanide.** It is obvious that in this case,

Deceased.

*Later, one of the authors suggested another method of removing the silver sulfide from the gelatin layers: treatment with a solution of thiourea, acidified with hydrochloric or sulfuric acid [3]. There will be a separate communication on the solubility of silver sulfide in acid solutions of thiourea.



where R =



Equation

too, as in the case of the processes previously described [1], the reduction of the azo dye takes place, the silver of the photographic image being oxidized at the same time, and converted into Ag_2S as a result of the presence of S^{2-} ions.

In order to isolate and identify the products of the reaction, the process of reduction of the azo dye was carried out in glass. The dye Direct Pure Blue was chosen for investigation, and specially purified for this purpose. The metallic silver was obtained by the reduction of an ammoniacal solution of silver oxide with a dilute solution of formaldehyde, followed by filtration, washing, and drying at $110-115^\circ$.

The dye was heated with a solution of sodium sulfide in the presence of an excess of metallic silver. After a half hour of boiling with a reflux condenser, complete decolorization of the solution took place. After cooling, o-dianisidine and silver sulfide were found in the precipitate. However, the amount of the latter corresponded only to approximately 50% of the dye, which was reduced according to the Equation (see above).

We found that this dye was also reduced directly by sodium sulfide at the boiling point, although this process took place much more slowly than the reduction in the presence of metallic silver. It is obvious that in the case where the dye is heated with a solution of sodium sulfide in the presence of metallic silver, the reduction takes place both by means of the metallic silver as well as directly by the sodium sulfide.

During the treatment of the colored photographic layers containing the silver image with a solution of sodium sulfide (at room temperature) the reduction takes place, apparently, only in accord with the equation given above. There is no doubt that the course of this reaction at room temperature is dependent upon the high degree of dispersion of the metallic silver in the photographic image.

EXPERIMENTAL

1. The purification of the dye Direct Pure Blue was carried out by a slight alteration of the method proposed by Markuse [4]. 25 g of the technical dye was dissolved in 175 ml of distilled water by heating to the boiling point. The solution was filtered, and to the hot filtrate 65 g of sodium acetate was added. It was allowed to stand overnight, until the dye had completely precipitated. The dye was filtered off, dissolved in 100 ml of distilled water by heating to boiling, and again salted out with sodium acetate. The precipitated dye was filtered off, and treated with alcohol in a Soxhlet apparatus to remove sodium acetate, then

dried at 100° for 12 hours. The degree of purity of the dye was tested by converting the sodium into the sulfate, and weighing the latter.

0.1238 g dye: 0.0344 g Na₂SO₄.

Found %: Na 8.99.

C₃₄H₂₄O₁₆Na₈S₄Na₄. Computed %: Na 9.27.

2. The reduction of Direct Pure Blue with silver in a solution of sodium sulfide. In a flask containing a reflux condenser, there were placed 6.8 g of the dye Direct Pure Blue, 250 ml of water, 3.9 g of technical (60%) sodium sulfide, and 10 g of powdered silver, and the mixture was heated to boiling. After a half hour of boiling with a reflux condenser, the intense blue color disappeared, and a brown solution was obtained. After cooling, the precipitate was filtered off and washed with small portions of hot water.

From the cooled wash water o-dianisidine was obtained in the form of brownish crystals, which were recrystallized from water and dried at 90°. Weight 0.65 g, which amounted to 39% of theory. M.p. 135-136° (according to the data in the literature, the m.p. is 137° [5]).

After the dianisidine had been washed out, the precipitate was a mixture of metallic silver and silver sulfide. In order to separate them, the precipitate was treated with a concentrated solution of potassium cyanide (15 g of KCN in 25 ml of water), and the silver sulfide went into solution in the form of a complex salt. The silver was filtered off and washed with a concentrated solution of potassium cyanide until a test of the filtrate with dilute water did not result in the formation of silver sulfide.

After this, the silver was washed on the filter with water, and dried at 110°. Weight 5.74 g. The filtrate, together with the washings, was diluted with water. The silver sulfide that was thus precipitated was filtered off, washed with water, and dried. Weight 3.49 g, which corresponded to 3.69 g of the dye according to the equation given above.

3. The reduction of Direct Pure Blue with sodium sulfide. A solution of 1.7 g of the dye Direct Pure Blue and 1.63 g of technical sodium sulfide in 150 ml of water was boiled with a reflux condenser, complete disappearance of the color taking place in the course of 40 to 45 minutes. After cooling, the o-dianisidine was separated in the form of brownish crystals with m.p. 132°. The dianisidine was not subjected to further purification.

SUMMARY

1. It has been found that several azo dyes are reduced by metallic silver in a solution of sodium sulfide upon heating to boiling, the silver being converted into silver sulfide.

2. A similar process of reduction also takes place when the colored azo dyes in the gelatin layers containing photographic images are treated with a solution of sodium sulfide. In this process, the dye is decolorized in the portions containing photographically developed silver, and the latter is converted into silver sulfide. This process, contrary to the patent data, takes place even without the addition of a reducing agent.

LITERATURE CITED

- [1] G.I. Arbuzov, Kinophoto-Chem. Ind., 5, No. 5, 31 (1939); 6, No. 6, 61 (1940).
- [2] B. Gaspar, French patent 727,168, 5/11/1931.
- [3] G.I. Arbuzov, Authors certificate No. 58,982, 11/21/1938.
- [4] K.M. Markuze, For the Reconstruction of the Textile Industry, 13, No. 12, 47 (1934).
- [5] J. Moir, Chem. Zentr., 1914 II, 327.

Received January 11, 1949.

THE PREPARATION OF FREE IMIDOSULFAMIDE AND ITS PROPERTIES

A. V. Kirsanov and Yu. M. Zolotov

Department of Organic Chemistry of the J.V. Stalin Dniepropetrovsk Metallurgical Institute

The new method of preparing the salts of imidosulfamide [1] recently discovered permits us to begin an investigation of the chemistry of this interesting and little investigated compound.

The first attempt to obtain imidosulfamide was made in 1888 [2] by Mente. From the products of the interaction of ammonium carbamate and the acid chloride of pyrosulfuric acid, Mente obtained a substance which he took to be imidosulfamide. Further investigation showed [3] that Mente had erred, and that his substance was definitely not imidosulfamide. In 1901, Hantzsch and Hall [4] decomposed the silver salt of cyclic trisulfimide with hydrogen sulfide (in his review of the work, Audris [5] erroneously reported that he used hydrogen chloride), and obtained in very small yield a substance which he took to be the free cyclic trisulfimide. This substance contained 3% less sulfur than theory required. Therefore, Hantzsch and Hall assumed that this substance contained chemically bound water, and had the composition $(\text{NH}\cdot\text{SO}_2)_3\cdot\text{H}_2\text{O}$. This composition corresponded to the analytical data. However, this assumption was incorrect, and after four years, in 1905, Hantzsch and Shtuer [3] showed that in the decomposition of the silver salt of trisulfimide with hydrogen sulfide, or, better, with hydrogen cyanide, the cleavage of one of the three SO_2 groups took place, and instead of the cyclic trisulfimide, there was obtained imidosulfamide. Hantzsch and Shtuer explained this cleavage by the hydrolytic action of the water, which, in their opinion, could not in any way be removed from the original products of the reaction. The yield of free imidosulfamide from the silver salt of trisulfimide amounted in only one especially successful experiment to 5% of the weight of the silver salt, was usually considerably lower, and fell to almost nothing if the original products were not freed from moisture in the most careful way. Hantzsch and Hall, on the basis of certain indirect data (see below), arrived at the conclusion that imidosulfamide in aqueous solutions even at 0° was instantly hydrolyzed according to the equation:



They were led to this conclusion by the determination of the molecular weight of imidosulfamide in aqueous solutions, and the isolation, by a fairly complicated method, of small amounts of sulfamide and sulfaminic acid from the aqueous solutions of imidosulfamide. Hantzsch and Shtuer explained the intensely acid reaction of imidosulfamide by the formation of sulfaminic acid, but decided, also indirectly, that during the solution of imidosulfamide in aqueous solutions of alkali, salts of imidosulfamide were formed, that is, that imidosulfamide was an acid. Of the salts of imidosulfamide, Hantzsch and Shtuer obtained only the silver and the ammonium salts, concerning whose properties cf. the preceding

paper [1] and below. As will be shown in this paper, Hantzsch and Shtuer drew a number of incorrect conclusions, chiefly because they based their considerations to a considerable degree on indirect data and made several experimental errors. None the less, their great service consisted in the isolation and preparation of imidosulfamide in pure form, and at that time this was connected with very great experimental difficulties.

In 1910, Efraim and Gurevich [8] reported that under the action of sulfur chloride on liquid ammonia, they were able to obtain "almost pure imidosulfamide", and that from the reaction products it was possible "to obtain at will either the pure silver salt of imidosulfamide or the pure silver salt of sulfamide". In addition, in the general part of their paper, there were a number of other reports on the properties of imidosulfamide. However, in the experimental part of the article there was not a single fact that would unambiguously confirm these results. All the conclusions of Efraim and Gurevich were based only on indirect data, namely, on the analyses of individual substances, which permitted them to draw the most various conclusions. Not a single substance was in pure form. They gave not a single physical constant of the products obtained. There would be no need to analyze this unsubstantial work, except that the conclusions of Efraim and Gurevich were listed in the review paper by Audris [5] without any criticism, and have been taken over into reference books and textbooks. It is therefore necessary to demonstrate the complete lack of foundation for the conclusions of Efraim and Gurevich with regard to the formation and properties of imidosulfamide. Efraim and Gurevich made their claim that they obtained the almost pure silver salt of imidosulfamide only on the basis of an analysis of this salt, and they listed no other data. From the analytical data [8], the authors calculated the formulas $\text{NAg}(\text{SO}_2\text{NHAg})_2 \cdot 19\text{H}_2\text{O}$ and $\text{NAg}(\text{SO}_2\text{NHAg})_2 \cdot 46\text{H}_2\text{O}$; it is not known how they determined the content of water. There is only a figure for "water found", but there is no figure for "loss of weight on drying", and it is not indicated how the drying was carried out. At the same time, the analytical data, with no less accuracy, conform to the formulas $\text{NHAg} \cdot \text{SO}_2 \cdot \text{NAg} \cdot \text{SO}_2 \cdot \text{NAg} \cdot \text{SO}_2 \cdot \text{NHAg} \cdot 26\text{H}_2\text{O}$ and $\text{NHAg} \cdot \text{SO}_2 \cdot \text{NAg} \cdot \text{SO}_2 \cdot \text{NAg} \cdot \text{SO}_2 \cdot \text{NHAg} \cdot 61\text{H}_2\text{O}$.

Thus, the silver salts of Efraim and Gurevich, according to their analytical data, could be both salts of imidosulfamide and salts of higher polysulfamides, and most probably, were mixtures and not individual compounds. On page 147 there is given still another analysis, which in the opinion of Efraim and Gurevich corresponded to the formula: $\text{NAg}(\text{SO}_2\text{NHAg})_2 \cdot 3\text{H}_2\text{O}$. In this analysis, the discrepancy between the computed and the found sulfur amounts to one percent, in absolute value, which corresponds to 8.6% of the sulfur content (computed 11.63%, found 10.63%). But even this did not embarrass the authors. They write: "The discrepancy with regard to the sulfur is to be explained by the small admixture of the silver salt of sulfamide". However, the admixture of the silver salt of sulfamide was not confirmed by the slightest analytical or experimental data.

The method of obtaining the silver salts adopted by Efraim and Gurevich fairly definitely indicates that their salts could not have contained the silver salts of imidosulfamide. The fact is that the monosilver salt of imidosulfamide is very difficultly soluble in water, and precipitates from weakly acid or neutral solutions (Hantzsch [3,4], and our data [1]). Therefore, if imidosulfamide and the silver ion were in solution, the salt would have precipitated from the weakly acid or neutral solution. Moreover, Efraim and Gurevich analyzed a second fraction from the precipitation with ammonia of the solutions which contained an excess of silver. Further, from the neutral solution, even in the presence of a great excess of silver, only the monometallic silver salt of imidosulfamide precipitates, [1]; the salts of Efraim and Gurevich were supposed to contain 3 atoms of silver per molecule of imidosulfamide. Consequently, the trimetallic

salt could not have precipitated (if it existed at all, which is very probable) from the neutral solution. It could precipitate only from an ammoniacal alkaline one. Let us ask then, why, before the solution was neutralized, there was no precipitation of the crystalline, characteristic monometallic salt, which is very difficultly soluble in water, and had been already described by Hantzsch. Probably because these solutions did not contain imidosulfamide. But then the salts of Efraim and Gurevich could likewise not be salts of imidosulfamide.

Thus, the conclusions of Efraim and Gurevich with regard to the formation of imidosulfamide during the reaction of sulfuryl chloride and ammonia must be considered completely unfounded. It is very probable that in this reaction a small quantity of imidosulfamide is in fact obtained, but no one has as yet demonstrated it in any manner. All the results of Efraim and Gurevich on the formation and properties of imidosulfamide should be stricken out of the scientific and reference book literature.

In a detailed consideration of the results of the work of Hantzsch [3], the most surprising thing appears to be the extremely easy saponification of imidosulfamide with water. It is known that many acids, which are very unstable in the free condition and in the form of salts, give stable amides. Thus, for example, acetoacetic acid and its salts lose carbon dioxide with extreme ease, while the amides of acetoacetic acid are stable [7], not too easily saponified compounds. The salts of imidosulfuric acid in aqueous solution at room temperature are completely stable [8]. It would appear that imidosulfamide, being a complete amide of imidosulfuric acid, should be more difficult to saponify than the salts of imidosulfuric acid. However, according to the data of Hantzsch [3], even at 0°, imidosulfamide in aqueous solution is instantaneously saponified. For some reason or other, in this case, amidation (according to Hantzsch's results) does not make an unstable acid more stable, but rather works the other way, as the free imidosulfuric acid is saponified at room temperature in aqueous solution fairly slowly, [9].

On the basis of these considerations, we doubted the correctness of Hantzsch's experimental data, and decided to attempt to obtain free imidosulfamide by the decomposition of its salts in aqueous solutions of strong acids, followed by as rapid evaporation of the water as possible at as low temperatures as possible. The very first experiment showed the correctness of our conclusions and the incorrectness of Hantzsch's results. By decomposing the sodium salt of imidosulfamide in aqueous solution with 0.9 equivalent of sulfuric acid at 0°, and subsequent evaporation at 0°, we were able to obtain free imidosulfamide with a yield of 80% of the theoretical. Later, it became clear that the evaporation could be carried out at a higher temperature. The method of isolating and purifying the imidosulfamide was somewhat improved and simplified, and it was possible to raise the yields to almost 90%, computed on the basis of the recrystallized sodium salt. In order to decompose the salt, it was very convenient to use a mixture of 90% of the theoretical amount of sulfuric acid and a small excess of sulfaminic acid. Thus, free iminosulfamide becomes a thoroughly accessible substance, and this made it possible to begin a more detailed investigation of its physical and chemical properties. Hantzsch gives for the completely purified imidosulfamide a melting point of 168°. The crude preparation obtained by us melted from 154-170°; after recrystallization, at 162-164°; and after a second recrystallization at 167-169° (uncorrected). Subsequent recrystallizations did not raise the melting point of the substance. Even the purest samples, upon slow heating in a capillary, began to "sinter" several degrees below the melting point.

Imidosulfamide is very readily soluble in water and in acetone, readily soluble in alcohol and in ethyl acetate, and practically insoluble in benzene. The process of solution in water and acetone is accompanied by an appreciable

absorption of heat. In 100 g of solutions saturated at 20°, there are contained: in water, more than 29.1 and less than 30.4 g; in acetone, more than 33.6 g and less than 35.9 g; in alcohol, more than 8.9 and less than 9.7 g, in ethyl acetate, 4.79 g, in ethyl ether, 0.526 g, in benzene, 0.00 g, in a mixture of acetone and benzene (1:3) about 0.64 g.

Hantzsch recrystallized imidosulfamide from hot ethyl acetate. However, this method of purification is connected with great losses, as the difference in solubilities in the boiling and cold solvent is not very great. In addition, during the recrystallization of the imidosulfamide from boiling or hot ethyl acetate, it is not possible to obtain a completely pure product. Apparently, upon heating even thoroughly purified imidosulfamide, there is a slow decomposition as a result of the reaction with traces of water, or possibly, with the solvent (cf. experimental part). Therefore, the recrystallization of imidosulfamide must be carried out without heating. The best results are obtained if the crude imidosulfamide is dissolved at room temperature in absolute ethyl acetate, the filtered solution evaporated to dryness in vacuum at room temperature, the residue dissolved in a small amount of absolute acetone, and 3 volumes of benzene added to the solution. Upon further recrystallization, the compound is dissolved in acetone and benzene is added. The preliminary treatment with ethyl acetate is necessary to remove small amounts of sulfaminic acid, which is fairly appreciably soluble in acetone (about 0.3 g per 100.0 g of solution).

The imidosulfamide thus obtained is in the form of snow-white needle-shaped crystals with an intense acid taste. Upon slow evaporation of solutions of imidosulfamide in acetone or in ethyl acetate, it is possible to obtain it in the form of beautiful large needles, but the melting points of such preparations are 1 or 2° lower than those of the preparations obtained by precipitation with benzene from a solution in acetone or ethyl acetate. The composition of imidosulfamide corresponds to the formula $H_5N_3S_2O_4$. The molecular weight, determined cryoscopically, corresponds to half the molecular weight computed for this formula. Upon complete hydrolysis of imidosulfamide, an almost quantitative yield of sulfaminic acid and sulfamide can be obtained, in accordance with the equation



All these facts, as well as those given below, very strictly show that this preparation actually is imidosulfamide with the structure $NH_2 \cdot SO_2 \cdot NH \cdot SO_2 \cdot NH_2$. Imidosulfamide is a strong acid, and can be titrated accurately in the presence of methyl orange or phenolphthalein. Its aqueous solutions are dissociated to a considerable extent. According to a colorimetric determination, the 0.01 N solution has a pH of 2.25, and the 0.001 N has a pH of 3.05. The determination of the molecular weight at lowered temperature by the freezing of the aqueous solutions also shows that in 0.01 to 0.03 N solutions, imidosulfamide is almost completely dissociated.

In order to find an explanation for the speed of hydrolysis of imidosulfamide in aqueous solutions, we proposed to trace it by means of the change in the refraction of the solutions with time at different temperatures. Unfortunately, we were forced to discard this method, as the refraction of an 0.8 N aqueous solution of imidosulfamide and the refraction of an equimolecular solution of sulfaminic acid and sulfamide differed from each other very little (n_D^{20} 1.333 and 1.349).

The measurement of the electrical conductivity also could not be utilized for the control of the course of hydrolysis, as the electrical conductivities of imidosulfamide and sulfaminic acid solutions, according to the data of Hantzsch, are practically identical [3]. Comparatively satisfactory results could be obtained by a fairly complicated method which utilized the considerable difference in solubility between sulfaminic acid and imidosulfamide in ethyl acetate (cf. Experimental section). After the solution had been hydrolyzed, it was cooled, and the water

removed by evaporation in vacuum at a temperature below 10°. The dry residue was carefully extracted with dry ethyl acetate, and the insoluble sulfaminic acid was dissolved in water and titrated with a solution of alkali. It was found that at 20°, in approximately 0.25 N solutions, the velocity constant of the hydrolysis of imidosulfamide, when multiplied by 10⁴, equaled 0.111; at 40° it was 1.78, and at 50°, 6.17. Thus, the time of hydrolysis of half the substance at 50° was about 19 minutes, at 40° about 65 minutes, and at 20° about 17.3 hours. The reaction was of the first, or more accurately, of the pseudofirst, order. The temperature coefficient between 20 and 40° was 4.00, and between 40° and 50° it was 3.47. It is necessary to emphasize that these data are not very accurate. The discrepancies between the constants found for 50° reached 5%. This is completely comprehensible as the method itself is not very accurate, because of the fairly lengthy time of evaporation and the need for introducing a correction for the solubility of sulfaminic acid in ethyl acetate. In addition, the apparatus used permitted the temperature to be kept constant in the experiments at 40 and 50° only with an accuracy of $\pm 0.5^\circ$. This resulted in some surprisingly great differences in the temperature coefficient between 40 and 50° and between 20 and 40°. It is probable that this difference is the result of the insufficient accuracy of the constant found for 40°, as it is improbable that hydrolysis took place by two different reaction mechanisms.

Despite the low accuracy, probably of the order of $\pm 5\%$, the data obtained give a clear picture of the velocity of the hydrolysis of imidosulfamide in aqueous solutions, and completely, "quantitatively" refute the conclusions of Hantzsch on the instantaneous hydrolysis of imidosulfamide during its solution in water.

Several salts of imidosulfamide were obtained. The ammonium salt was easily obtained by mixing alcoholic solutions of imidosulfamide and ammonia. The salt is very readily soluble in water, very difficultly soluble in cold alcohol, and somewhat better soluble in hot. It crystallizes as transparent, fine needles, which are not hygroscopic, and do not contain water of crystallization. The composition of the salt corresponds to the formula $(\text{NH}_2\text{SO}_2)_2\text{N}\cdot\text{NH}_4$. The aqueous solutions are neutral to Congo red. Upon heating in a capillary, the ammonium salt softens at 114° and melts at 115-118°, being converted into a cloudy liquid.

The silver salt was obtained in an almost quantitative yield by the neutralization of an aqueous solution of imidosulfamide with caustic soda, and the addition to this solution of an equivalent amount of silver nitrate. The properties of the silver salt obtained from free imidosulfamide accurately correspond to the properties of the salt obtained directly from the sodium salt of imidosulfamide synthesized from sulfamide by the action of alkali, or from the crude ammonium salt of imidosulfamide synthesized from sulfamide by the action of pyridine. The identity of the properties of the silver salts obtained from free imidosulfamide and from its salts shows without any doubt that when free imidosulfamide is obtained from its salts no transformation takes place in the imidosulfamide anion. (For the properties of the silver salt, see one of the preceding papers [1]).

The sodium salt was obtained by neutralizing an aqueous solution of imidosulfamide and evaporating the solution in vacuum. Its properties agree accurately with the properties of the sodium salt obtained by the action of a solution of caustic soda on sulfamide [1]. The barium salt is very readily soluble in water, and very difficultly soluble in alcohol. Upon precipitation from aqueous solutions with alcohol, it comes out in the form of oily drops, which are slowly transformed into fine needle-shaped crystals. Upon rapid heating, it decomposes at 228-233°. It does not contain water of crystallization. Its composition corresponds to the formula $\text{Ba}(\text{N}_3\text{H}_4\text{O}_4\text{S}_2)_2$. The mercury and the copper salts (decomp. temp. 181-183°) were also obtained, but not investigated in detail.

The pyridine salt of imidosulfamide was obtained by the addition of pyridine to an alcoholic solution of imidosulfamide. The salt is very difficultly soluble in cold alcohol, somewhat more readily soluble in hot alcohol. It crystallizes as large transparent needles. It is very readily soluble in cold water, the aqueous solutions being neutral to Congo red. It is difficultly soluble in cold acetone, appreciably more soluble in boiling acetone, and it can be recrystallized from acetone. It does not contain water of crystallization. Its composition corresponds to the formula $C_5H_5N \cdot H_5N_3S_2O_4$. Upon heating in a capillary, it begins to soften at 130° , and melts at $132-134^\circ$, forming a cloudy liquid which becomes transparent at 135° .

The α -aminopyridine salt is obtained by the addition of an alcoholic solution of aminopyridine to alcoholic solution of imidosulfamide. It is very difficultly soluble in cold alcohol and cold acetone, somewhat more soluble in the hot solvents. It crystallizes in very fine needles. It is easily soluble in water, with a neutral reaction to Congo red. Its composition corresponds to the formula $C_5H_4N \cdot NH_2 \cdot H_5N_3S_2O_4$. Upon heating in a capillary, it softens at $127-128^\circ$, and melts at $130-132^\circ$, being converted into a transparent liquid. The air-dried salt does not contain water of crystallization.

The aniline salt is obtained by the addition of aniline to an alcoholic solution of imidosulfamide. It slowly precipitates from the dilute alcoholic solution in the form of fine shining prisms and long needles. Upon standing in solution, the needles gradually disappear, and the prisms increase in number and volume. After two days, all the needles disappear, and only the large shining prisms remain. From a concentrated solution it precipitates rapidly only in the form of needles. The salt is readily soluble in water with an acid reaction to Congo red. It is readily soluble in boiling alcohol, and much more difficultly soluble in cold alcohol. It is readily soluble in cold acetone, and much more readily soluble in hot. Its composition corresponds to the formula $C_6H_5NH_2 \cdot H_5N_3S_2O_4$. Both the needles and the prisms and their mixtures melt at the same temperature of $121-122^\circ$, forming a transparent, colorless liquid.

The dimethylaniline salt precipitates from concentrated alcoholic solutions in the form of oily drops. An investigation of the properties of imidosulfamide and its derivatives is being continued in other directions.

EXPERIMENTAL

The preparation of free imidosulfamide. 0.1 mole of the sodium salt of imidosulfamide (19.7 g) (Note 1) was placed in a round-bottomed flask of 300 ml capacity and dissolved in 25.0 ml of water. The solution was cooled to 0° and 9.0 ml of 10 N sulfuric acid added with stirring, the acid also being cooled to 0° . Then 0.03 mole of carefully powdered sulfaminic acid (2.71 g) was added to the solution, and the solution stirred by hand until the solution of the sulfaminic acid was complete. The flask was joined (Note 2) to a ball condenser used as a reflux, and this in turn was joined to a receiver cooled with a freezing mixture to -15 or -20° (Note 3) and to a vacuum. After the air had been evaporated to a pressure of 1 or 2 mm, the flask was placed in a water bath heated to 20° (Note 4), and the solution quickly evaporated to dryness with continuous very energetic shaking of the flask (Note 5). Usually, under the conditions described, evaporation required 20 to 25 minutes. Toward the end of the evaporation, for greater ease in the final drying, we tried to spread the solid residue as uniformly as possible over the entire inside surface of the flask. In order to remove the water completely, the drying of the solid crystalline residue was continued under the same conditions for an additional hour. Then 50.0 ml of pure dry acetone was added to the dried residue (Note 6), the mixture vigorously shaken, and the solution, together with the solid matter, transferred

to a funnel to be filtered with suction through a porous glass plate (Note 7). The precipitate was carefully ground with a glass ram, and the acetone solution removed with suction. The thoroughly pressed residue was washed 4 times with 25.0 ml portions of dry acetone, the acetone being carefully mixed with the residue each time until there was a homogeneous, half liquid porridge. The combined acetone extracts were evaporated in a vacuum in a round-bottomed flask of 300 ml capacity at a water bath temperature which did not exceed 30° (Note 8). The residue consisted of a dry crystalline substance which amounted to 16.5-17.5 g. In order to remove the sulfaminic acid, the product was extracted twice with 200.0 ml portions and 4 times with 20.0 ml portions of pure dry ethyl acetate (Note 9). The extracts were filtered through a folded filter and evaporated in vacuum to dryness at a temperature which did not exceed 30° (Note 8). After an hour's drying, the residue contained 15.8-16.2 g, i.e., 90.2-92.5% of the theoretical amount of imidosulfamide, in the form of a colorless, finely crystalline powder. The product apparently contained a very small amount of some impurity, which was detected by its sharp, caustic odor. This odor did not disappear even upon very lengthy drying in vacuum, but disappeared completely after the first recrystallization, and consequently was not a property of imidosulfamide, but was the result of some sort of high-boiling impurity. In addition, the product doubtless contained a small amount of sulfaminic acid, which is slightly soluble even in absolute ethyl acetate (about 0.1 g per 100.0 g of saturated solution). This explained the comparatively low melting point of the crude imidosulfamide, which was 154-160°. In order to purify the crude imidosulfamide (15.8-16.2 g) it was dissolved in 45-50 ml of dry acetone (Note 6), the solution filtered, the flask and the filter washed with 25.0 ml of acetone, and about 100 ml of absolute benzene added to the filtrate. After several seconds, crystallization began, and after several minutes, the solution was filled with a solid mass of transparent, well-shaped needle-like crystals. After 20 minutes, the solution and the precipitate were vigorously stirred, and an additional 125 ml of benzene was added. After an hour, the imidosulfamide was filtered off with suction, washed 3 times with 15 ml portions of an acetone-benzene mixture (1:3), and dried in a vacuum desiccator. Thus, 13.7-13.9 g of imidosulfamide was obtained in the form of snow-white needle shaped crystals with m.p. 162-164°. Upon evaporating the mother liquor and the residue from the recrystallization to dryness in vacuum, as described above, we could obtain an additional 1.5 to 1.7 g of the product of the same quality. The total yield of recrystallized imidosulfamide was 15.2 to 15.6 g, i.e., 86.7-89.0% of the theoretical amount. For analytical purposes, the imidosulfamide was recrystallized as described above once more (Note 10). The twice recrystallized imidosulfamide melted at 164-166° (uncorrected), or 167-169° (corrected). A third recrystallization did not change the melting point of the preparation.

Note 1. We used the unrecrystallized sodium salt of imidosulfamide, obtained from sulfamide by the action of alkali (see preceding work) and dried in vacuum at 80°. It was unnecessary to use the recrystallized sodium salt, as the slight increase in yield did not repay the expenditure of time and the loss of material in recrystallization.

Note 2. The union of the flask and the condenser had to be made flexible, as during the evaporation, it was necessary to shake the flask vigorously and continuously.

Note 3. As a receiver we found it convenient to use a Wurtz flask with a capacity of 500 ml. The freezing mixture was the usual one, but it had to be carefully prepared.

Note 4. If the pressure in the system is not less than 2 mm, the receiver immersed in a cooling mixture of -15 to -20°, and the flask vigorously shaken, then at a bath temperature of +20° the temperature inside the flask will not rise

above +2 or 3°, down to the moment of complete solidification of the residue, and thus there is no danger that the imidosulfamide will be quickly hydrolyzed.

Note 5. Instead of shaking the flask, it is possible to carry out the evaporation with a fine capillary which leads to the air, but in this way it is more difficult to obtain a good vacuum, and the evaporation takes place more slowly.

Note 6. The acetone, boiling within the limits of a single degree, was dried with calcium chloride for 10 days, filtered, and again distilled.

Note 7. A No. 1 funnel, with 45 mm diameter, is suitable. Part of the dry residue will adhere closely to the walls of the flask; in this case it is carefully scraped off with a bent glass rod.

Note 8. It is convenient to carry out this evaporation with a receiver cooled to -15° or -20°. In order to attain the lowest possible pressure, the receiver and the vacuum pump should be separated, and the evaporation conducted in a closed evacuated system, not connected with the pump. If the system is not completely hermetical, from time to time, for several seconds, it may be joined to the pump. In a well-constructed apparatus this will not be necessary. Thus, little solvent will be lost, and the pump will not be harmed too much.

Note 9. The ethyl acetate used did not contain alcohol, and boiled within a range of 0.5°. Ordinary ethyl acetate was washed 3 times with a solution of calcium chloride and distilled in a column with complete reflux condensation, with 12 theoretical plates.

Note 10. Recrystallization from boiling absolute ethyl acetate was not suitable, as the difference in solubilities is not very great. It is possible to crystallize imidosulfamide from ethyl acetate containing from 1 to 3% alcohol. In this case, the difference of solubilities is appreciably greater. However, in recrystallizing from hot solvents it is more difficult to obtain a completely pure preparation (see below). In order to obtain larger crystals, it is necessary to precipitate imidosulfamide from more dilute solutions. It is also possible to dissolve imidosulfamide in ethyl acetate or acetone and precipitate it with ordinary ether or benzene or carbon tetrachloride.

The solubility of imidosulfamide. 1. In water. To 0.875 g of pure imidosulfamide, water was added in 0.5 ml portions. After each addition, the small flask containing the mixture was immersed in a water thermostat, which was heated to 20±0.5°, and shaken for 10 minutes.

Then the water was added in 0.05 ml portions. After the addition of 2.10 ml there remained a barely noticeable residue, and after the addition of 2.15 ml of water, a completely clear solution was obtained. On repeating the experiment, a completely clear solution was obtained after the addition of 2.05 ml of water. Therefore, in order to compute the solubility, we took the limiting amounts of water needed to dissolve 0.875 g of imidosulfamide, 2.00 and 2.15 ml. Hence, 100 g of an aqueous solution of imidosulfamide saturated at 20° contained less than 30.4 g and more than 29.1 g of the substance.

2. In acetone. The determination of the solubility was carried out in the same way as for water. 2.0 g of imidosulfamide did not dissolve completely in 4.5 ml of acetone (d 0.792) at 20° and did dissolve in 5.0 ml. Hence, the solubility in acetone is less than 35.9 g and more than 33.6 g per 100 g of solution saturated at 20°.

3. In alcohol. 0.875 g of imidosulfamide did not dissolve completely in 10.0 ml of 96° alcohol (d 0.812) at 20°, and did dissolve completely in 11.0 ml. Hence, the solubility in 96° alcohol is less than 9.7 g and more than 8.9 g per 100 g of solution saturated at 20°.

4. In ethyl acetate. A sample of solution saturated at 20° was evaporated

The process of the solution of the imidosulfamide in water was accompanied by a considerable adsorption of heat. After the addition of 2.0 ml of water and shaking for 10 minutes, there remained a slight amount of

to dryness at 20°. The weight of solution was 14.65 g, the weight of the dry residue 0.7020 g. 100 g of the solution saturated at 20° contained 4.79 g of imidosulfamide.

5. In diethyl ether. A sample of solution saturated at 20° weighed 35.0 g, the dry residue 0.184 g. 100 g of the solution saturated at 20° contained 0.526 g of imidosulfamide.

6. In benzene. The sample of solution saturated at 20° weighed 10.0 g, the dry residue 0.0002 g. 100 g of the solution saturated at 20° contained 0.002 g of imidosulfamide.

7. In a mixture of acetone and benzene (1:3). The mother liquor from the third recrystallization of imidosulfamide (see above) was weighed, and then evaporated to dryness in vacuum. The weight of solution was 329.0 g, the weight of material obtained 2.10 g; hence the solubility was about 0.64 g per 100 g of saturated solution.

The action on imidosulfamide of boiling ethyl acetate. 0.5 g of imidosulfamide with m.p. 164-166° was mixed with 10.0 ml of absolute ethyl acetate and the mixture boiled with a reflux condenser for 1 hour. The ethyl acetate was driven off in vacuum. The residue had m.p. 158-160°.

The isolation of the products of hydrolysis of imidosulfamide. A solution of 0.005 mole (0.875 g) of imidosulfamide in 20 ml of water was heated quickly to the boiling point and boiled for 15 seconds. After cooling, the solution was evaporated to dryness in vacuum (temperature of the water bath 30°, toward the end 40°). The dry residue was shaken for 20 minutes with 40.0 ml of absolute ethyl acetate, and the solution filtered. The residue was washed 4 more times with 5.0 ml portions of ethyl acetate, and dried in vacuum. Thus, 0.479 g of sulfaminic acid was obtained, and taking account of the solubility in ethyl acetate, 0.486 g, that is, 100% of the theoretical amount. The substance was in the form of a snow-white, finely crystalline powder, which melted at 202-204° and gave no depression of the melting point when mixed with known sulfaminic acid. After recrystallization from a mixture of water and acetone, large characteristic prisms were obtained, m.p. 204-205°. For the purpose of identification, a sample of the preparation was titrated with alkali. 0.2743 g required 5.60 ml of 0.5 N alkali, the computed value being 5.65 ml. The united ethyl acetate extracts were evaporated to dryness in vacuum. The residue was a colorless oil, which upon the introduction of a fragment of sulfamide quickly and completely crystallized, with the formation of the characteristic radial crystals of sulfamide. After drying in vacuum at 40° for an hour, the substance weighed 0.486 g, and taking account of the sulfaminic acid impurity (as a result of the solubility of the latter in ethyl acetate), 0.478 g, i.e., 99.6% of the theoretical amount. As a result of the contamination with sulfaminic acid (about 0.08 g, i.e., 0.4%) the sulfamide had a comparatively low melting point, 89-91°, which was 2° lower than that of the completely purified product. A mixed test melted at 91-93°. After recrystallization from ethyl acetate, the m.p. was 92-93°.

The determination of the solubility of sulfamide in ethyl acetate at 20°. In order to obtain the sulfamide quantitatively in the separation of the products of hydrolysis of imidosulfamide, it was necessary to know the solubility of the sulfamide in ethyl acetate. The determination was carried out in the usual manner. A mixture of 1.0 g of sulfamide and 10.0 ml of ethyl acetate was shaken for 20 minutes at 20°. Weight of solution 7.83 g, dry residue after evaporation in vacuum 0.0996 g. Hence, the solubility of the sulfamide was 1.28 g per 100 g of saturated solution at 20°, or about 1.15 g per 100 ml of solution, considering the specific gravity of the solution to be approximately the same as the specific

gravity of ethyl acetate. The molecular weight was determined:

0.0221 g substance: 10.0 g H_2O ; Δt 0.044°, 0.046°, 0.042°, 0.044°.

0.0500 g substance: 10.0 g H_2O ; Δt 0.102°, 0.104°, 0.100°, 0.102°.

Found: M 93.4, 91.2.

$H^+(N_3H_4S_2O_4)$. Computed: M 87.59.

1.0204 g, 0.7353 g substance: 0.5 N Alkali 11.6 ml, 8.4 ml.

Found: M 175.6, 175.2.

$N_3H_5S_2O_4$. Computed: M 175.18.

The pH of the aqueous solutions of imidosulfamide was determined colorimetrically. The 0.01 N solution had a pH of 2.25, the 0.001 N solution 3.05 at 20°.

Composition of the imidosulfamide. The sample of imidosulfamide was heated for the purpose of analysis with concentrated hydrochloric acid in sealed tubes at 130° for 6 hours. The sulfur was determined in the form of barium sulfate, the nitrogen in the form of ammonia.

0.1547 g substance: 0.4103 g $BaSO_4$; 5.25 ml 0.5 N acid.

0.1462 g substance: 0.3886 g $BaSO_4$; 4.95 ml 0.5 N acid.

Found %: S 36.43, 36.32; N 23.77, 23.66.

$N_3H_5S_2O_4$. Computed %: S 36.60; N 23.98.

The determination of the velocity of hydrolysis of imidosulfamide in aqueous solution

In order to determine the velocity of hydrolysis of the imidosulfamide, it was necessary to find a method of separating the imidosulfamide and sulfaminic acid. Orientation experiments showed that acetone and ethyl acetate (both being good solvents for imidosulfamide) dissolved little sulfaminic acid. Therefore, a quantitative determination of the solubility of sulfaminic acid in these solvents was carried out. This showed that acetone was completely unsuitable for the quantitative separation of imidosulfamide and sulfaminic acid, while ethyl acetate was suitable, although a correction was required for solubility in it.

The solubility of sulfaminic acid in acetone and ethyl acetate. For the determination we used carefully dried solvents and twice recrystallized sulfaminic acid.

1. In acetone at 15°. Direct determination. A sample of the saturated solution was evaporated in vacuum, and the residue titrated with alkali. A sample of 33.6 g (about 42.5 ml) required for neutralization 2.35 ml of 0.5 N alkali. Hence, the solubility was 0.339 g per 100 g, and about 0.268 g per 100 ml of solution saturated at 15°.

Indirect determination under the conditions of the hydrolysis experiments. An approximately 0.25 N solution of sulfaminic acid was prepared. The titration of 10.0 ml of this solution required 4.9 ml of 0.5 N alkali. 10.0 ml of this solution was evaporated to dryness in vacuum, and the residue was extracted at 15° once with 10 ml and 4 times with 5.0 ml portions of acetone, i.e., with a total of 30.0 ml of acetone. Titration of the insoluble portion required 3.10 ml of 0.5 N alkali. Hence, 0.875 g went into solution and the solubility was 0.291 g per 100.0 ml.

In acetone at 20°. A 36.4 g sample of the saturated solution (about 46.1 ml) required 3.2 ml of 0.5 N alkali for neutralization. Hence, the solubility was 0.426 g per 100.0 g and about 0.337 g per 100.0 ml of solution saturated at 20°.

2. In ethyl acetate at 20°. A 45.24 g sample of the saturated solution (about 50.4 ml) was used. After the ethyl acetate had been driven off in vacuum

0.13 ml of 0.5 N alkali was required for neutralization. Hence the solubility was 0.0139 g per 100.0 g or about 0.0125 g per 100 ml of saturated solution.

In a dry flask, previously immersed in the water of a thermostat, there was placed a sample of imidosulfamide (0.45 to 0.50 g), and 10.0 ml of water heated to the corresponding temperature was added. The flask and its contents were shaken until the substance dissolved, this required several seconds. After the period of hydrolysis had passed, the flask was transferred to a cooling mixture at -15° , and the liquid was then cooled to approximately $+5^{\circ}$. The flask was joined to a reversed condenser and to a receiving vessel cooled with a cooling mixture at -20° . The evaporation was carried out in a vacuum of 2 to 2.5 mm, while the flask was kept in a water bath heated to $+15^{\circ}$. In order to hasten the evaporation, the flask was shaken continuously and energetically. The evaporation was usually completed in 10 to 15 minutes. The dry residue was treated for 10 minutes with 10.0 ml of absolute ethyl acetate; during this treatment, the residue fell away from the walls of the flask and collected on the bottom in the form of a finely crystalline colorless powder. If the residue did not fall away, it was rubbed off with a bent glass rod. The solution with the residue was poured across a small, smooth filter, and the residue in the flask was extracted 5 more times with 5.0 ml portions of ethyl acetate. Special attention was paid to the quantitative washing of the filter. At the end of the extraction, the filter was dried together with the precipitate in it in the vacuum-desiccator, and the residue in the flask was dried in a vacuum. The sulfaminic acid on the filter was then quantitatively washed, by means of 15.0 ml of water, into the flask containing the residue, and the solution was titrated with 0.5 N alkali. In the computations, account was taken of the loss of sulfaminic acid because of the solubility in ethyl acetate. The results of the experiments are listed in the table.

Temperature	Duration, minutes	Sample, g	Ml 0.5 N alkali, plus correction (0.09 ml)	Hydrolysis, %	$K \cdot 10^4$	Temperature coefficient
$50 \pm 0.5^{\circ}$	10.0	0.4657	1.60	30.2	5.99	3.47
50 ± 0.5	20.0	0.4547	2.75	53.0	6.29	
50 ± 0.5	40.0	0.4686	4.15	77.6	6.23	
40 ± 0.5	40.0	0.4589	1.85	35.2	1.81	1.78
40 ± 0.5	80.0	0.4595	2.98	56.8	1.75	
20 ± 0.1	480.0	0.4515	1.43	27.6	0.109	4.00
20 ± 0.1	960.0	0.4541	2.39	46.5	0.113	

The refraction of an aqueous solution of imidosulfamide and of an equimolecular solution of sulfamide and sulfaminic acid. 0.004 mole of imidosulfamide (0.7007 g) was dissolved in water, in a calibrated flask of 5.0 ml capacity. In the same way, a solution was prepared of a mixture of 0.004 mole of sulfamide (0.3844 g) and 0.004 mole of sulfaminic acid (0.3884 g). The refraction (Abbe) of the first solution was n_D^{20} 1.333 and of the second n_D^{20} 1.349.

Salts of imidosulfamide. The ammonium salt. To a solution of 0.01 mole of imidosulfamide (1.75 g) in 30.0 ml of alcohol, 10.0 ml of a 1.0 N solution of ammonia in alcohol was added. The solution became cloudy, and then well-formed needle-shaped crystals began to precipitate. After several minutes, the entire solution "set". After a day, the precipitate was filtered off with suction, washed with alcohol, and dried in the air. The yield was 1.70 g, or 80% of theory. The air-dried ammonium salt of imidosulfamide lost about 0.1% of its weight upon drying in a vacuum at 80° . (For its properties, see general part of paper). For analysis, a sample was hydrolyzed by the usual method with hydrochloric

acid.

0.1262 g substance: 0.3049 g BaSO₄.

0.1534 g substance: 6.44 ml 0.5 N HCl.

Found %: S 33.18; N 29.39.

N₄H₈O₄S₂. Computed %: S 33.36; N 29.16.

The silver salt of imidosulfamide from free imidosulfamide. 0.01 mole of imidosulfamide (1.752 g) was dissolved in 25.0 ml of water. The solution was at once neutralized with 20.0 ml of 0.5 N alkali, and then 5.1 ml of a 2 N silver nitrate solution was added. The precipitation of the characteristic crystals of the silver salt of imidosulfamide began quickly. After 12 hours, the salt was filtered with suction, washed, and dried in the air. Yield 3.08 g, or 96.6% of theory. The properties and composition corresponded precisely to the properties of the salt obtained from the sodium salt without transformation into free imidosulfamide.

The sodium salt of imidosulfamide was obtained by neutralizing an aqueous solution of imidosulfamide with caustic soda, evaporating the solution in vacuum, and crystallizing from a small amount of water. The composition and properties were identical with the properties of the salt obtained directly from the reaction of sulfamide with caustic soda.

The barium salt of imidosulfamide. 0.005 mole of imidosulfamide (0.875 g) was added to a mixture of 0.003 mole of barium carbonate (0.59 g) and 3.0 ml of water. When the evolution of carbon dioxide ended, and the solution became neutral to Congo red, the excess of barium carbonate was filtered off with suction and washed 3 times with 0.5 ml portions of water. During evaporation, drops of the solution on the wall became a vitreous, transparent mass. Upon mixing the drops of solution with alcohol, oily drops precipitated. After prolonged rubbing with a stirring rod, these crystallized. Then 70.0 ml of alcohol was added to the main portion of the solution, plus a seed of the crystalline salt. Upon energetic stirring, the barium salt soon crystallized completely in the form of colorless, very fine needle-shaped crystals. After these had been filtered with suction, washed with alcohol, and dried in the air, 1.21 g of the barium salt of imidosulfamide was obtained, or about 95% of theory. The salt was readily soluble in water, very difficultly soluble in alcohol, and insoluble in ether and benzene. Upon rapid heating in a capillary, it decomposed at 228-233°. Upon slow heating, the moment of decomposition was almost unnoticeable. It did not contain water of crystallization.

0.3116 g substance: 0.1489 g BaSO₄.

Found %: Ba 28.13.

Ba(N₃H₄S₂O₄)₂. Computed %: Ba 28.28.

The copper salt of imidosulfamide. To a mixture of 1.0 g of freshly precipitated copper hydroxide and 3.0 ml of water, 0.005 mole (0.875 g) of imidosulfamide was added. The precipitate of copper hydroxide was gradually converted into a dark viscous, sticky mass, which could not be changed into a crystalline form. Upon the addition of an excess of ammonia, the precipitate went into solution, and soon beautiful violet crystals began to precipitate out, probably a copper compound containing ammonia, similar in nature to biuret. After the precipitate had been filtered with suction and washed with an aqueous solution of ammonia, about 0.4 g of beautiful violet crystals were obtained. In the air these quickly lost ammonia (determined qualitatively) and were converted into a blue crystalline powder, which decomposed at 181-183°. The analysis of the copper salt has not as yet been carried out.

The pyridine salt of imidosulfamide. To a solution of 0.001 mole of imidosulfamide (0.175 g) in 5.0 ml of alcohol, about 0.0011 mole of pyridine (0.09 ml)

was added. There was an immediate precipitate of needlelike crystals, which were filtered with suction after an hour, and washed three times with 1.0 ml portions of alcohol. Yield 0.24 g, or about 94% of theory. (For properties, see general section).

4.501 mg substance: 0.859 ml N₂ (18°, 755 mm).

Found %: N 22.25.

C₅H₅N·H₅N₃S₂O₄. Computed %: N 22.05.

The α-aminopyridine salt of imidosulfamide. This was prepared in the same way as the pyridine salt. From 0.001 mole of imidosulfamide, 0.25 g of the salt, or about 93% of theory, was obtained.. (For properties, see general section).

4.324 mg substance: 0.968 ml N₂ (18°, 755 mm).

Found %: N 26.09.

C₅H₆N·H₅N₃S₂O₄. Computed %: N 26.02.

The aniline salt of imidosulfamide. 0.005 mole of imidosulfamide (0.875 g) was dissolved in 10.0 ml of alcohol, and to the solution was added 0.0055 mole of freshly distilled aniline (0.5 ml). There was an immediate precipitate of large needle-shaped crystals. After an hour, they were filtered off with suction and washed 3 times with 1.0 ml portions of alcohol. Yield 0.8 g, or 60% of theory. If the same amount of imidosulfamide is dissolved in 25.0 ml of alcohol, and 0.5 ml of aniline is added, there is a slow formation of a mixture of prisms and needles. On standing the needles disappear, while the prisms increase in number and volume. (For properties, see general part).

5.002 mg substance: 0.899 ml N₂ (18°, 756 mm).

Found %: N 20.97.

C₆H₇N·H₅N₃S₂O₄. Computed %: N 20.97.

SUMMARY

1. Free imidosulfamide has been obtained and several of its properties have been investigated, including the velocity of hydrolysis in aqueous solutions.

2. It has been shown that some of the data about imidosulfamide in the literature do not correspond to the facts.

LITERATURE CITED

- [1] A.V.Kirsanov and Yu.M.Zolotov, J.Gen.Chem., 20, 1637 (1950).
- [2] Mente, Ann., 248, 267 (1888).
- [3] Hantzsch and Shtuer, Ber., 38, 1022 (1905).
- [4] Hantzsch and Hall, Ber., 34, 3430 (1901).
- [5] Audris and coworkers, Chem. Rev., 26, 49 (1940).
- [6] F. Efraim and M.Gurevich, Ber., 43, 138 (1910); F. Efraim and F. Mikhel, Ber., 42, 3833 (1909).
- [7] In literature cf: Beilstein, 4th ed., v III, p. 659.
- [8] Cf., for example, Berglund, Bull. Soc. chim. France (2), 25, 452 (1876).
- [9] Cf., for example, Divers and Haga, J.Chem.Soc., 61, 943 (1892).

Received December 23, 1948.

See CB translation p. 1699 ff.

BETAINE-LIKE COMPOUNDS

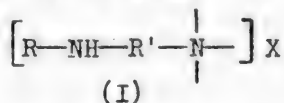
FORMED BY THE SPLITTING OFF OF A PROTON FROM THE NH GROUP

V. DERIVATIVES OF β -ANTHRAQUINONE SULFONIC ACID

A. M. Simonov and N. P. Anshukova

Laboratory of Organic Chemistry of Moscow Textile Institute

In previous papers [1] it was shown that quaternary ammonium salts with the structure (I), when subjected to the action of alkali, form internal salts (betaine-azenes), the ease of whose formation depends on the structure of the radicals R and R' attached to the NH group. It was found that the formation of betaines of the benzene series (R'-phenylene) took place with great ease if R was a 2,4-dinitrophenyl or a picryl group: the powerful mesomeric effect of these groups resulted in a high degree of mobility of the hydrogen in the NH group, and after the splitting off of the hydrogen, led to the stabilization of the betaine as a result of the diffusion of the negative charge of the azene N atom. The substitution of a phenylene ammonium group by the quinoline group, with a more powerful mesomeric effect, permitted the formation of salts which would still more easily undergo the transformation into bipolar ions. The formation of betaines took place with greater difficulty if the NH group was attached to a toluene sulfonyl radical, the influence of the latter on the NH group apparently consisting chiefly in a direct inductive effect on the S-atom.

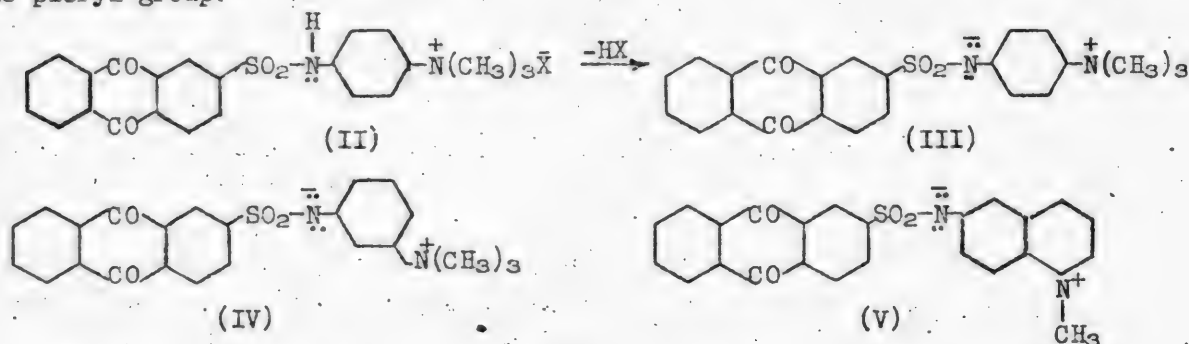


In this article, we consider the betaine-forming ability of ammonium salts of the structure (I), where R is the β -anthraquinone sulfonic acid radical. In order to obtain these salts, β -anthraquinone sulfonic acid hydrochloride was reacted with p-aminodimethylaniline, its meta isomer, or with 6-aminoquinoline, and the anilide formed was subjected to fusion with the methyl ester of p-toluenesulfonic acid.

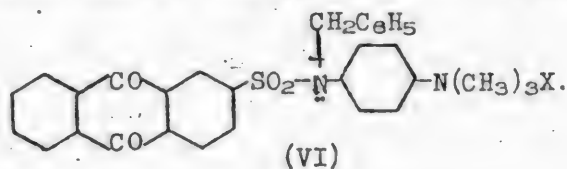
The β -anthraquinone sulfonic acid group should have a stronger influence than the p-toluenesulfonic acid group on the mobility of the hydrogen of the NH group to which it is attached: the accumulation of electrophilic CO groups in the nucleus attached to the SO₂ group opposes the drawing away of electrons from the nucleus of this group. This leads to the intensification of its polarizing influence on the NH group. We may, therefore, expect that the transformation into betaines of quaternary salts which contain the anthraquinone sulfonic acid group will take place more easily than that of the p-toluenesulfonic acid derivatives (R = p-CH₃C₆H₄SO₂). Experiment has confirmed this assumption. Upon adding to

The mutual influence of electrophilic groups attached to the benzene nucleus has been considered in detail by V. A. Izmailsky and A. E. Smirnov in an investigation of the colors of aryl amides of aromatic acids [3]. They found that the accumulation of electrophilic groups (NO₂, CO) in the acyl had the result of increasing the overall electrophilic properties of this system; this was evident for example in the intensification of the chromophoric properties of the acyl. This phenomenon was expressed with especial sharpness when these groups were in such a position as to result in the "opposition" of the respective polarizing influences ("counter-systems") for example, in the para-position.

an aqueous alcohol solution of salt (II) a dilute solution of caustic soda or ammonia, the betaine (III) quickly precipitates, while under these conditions the corresponding toluenesulfonyl derivative does not form, and can be obtained only by way of the dehydration of the base [2]. The formation of the meta isomer (IV) takes place just as smoothly as that of compound (III); in the former, the closeness of the positively charged N atom to the NH group is obvious, and this facilitates the splitting off of a proton from the latter. The betaine of the quinoline series (V) is formed with especial ease, its precipitation taking place upon the addition of even such a weak base as pyridine to an aqueous alcoholic solution of the original salt. Thus, in the quaternary salts under investigation, the anthraquinone sulfonyl group shows almost as powerful an influence on the NH group as the picryl group.



We also obtained the quaternary salt (VI), which differs from compound (II) by the fact that the mobile H atom in the NH group is substituted by a benzyl group. As was to be expected, the bond of the imide nitrogen with the benzyl group is very stable. Under the action of alkali on this compound, there is no formation of the betaine (III). This observation is an additional confirmation of the structure of the compounds of the class under investigation, as being internal salts formed by the splitting off of a proton from the NH group.



EXPERIMENTAL

4-(β-Anthraquinone sulfamino)-N,N-dimethylaniline (the p-dimethylamino anilide of β-anthraquinone sulfonic acid). The original hydrochloride of β-anthraquinone sulfonic acid was obtained by heating the sodium salt of this acid with phosphorus pentachloride in a solution of phosphorus oxychloride up to the boiling point for 4 hours [4]. The crystallization was from benzene or dichloroethane. M.p. 195-195.5°. 7 g of the hydrochloride of β-anthraquinone sulfonic acid was gradually added to a solution of 3.2 g of freshly distilled p-aminodimethylaniline in 25 ml of pyridine, and the gruel-like mixture was heated at 50° for 30 minutes. On the following day it was poured into 200 ml of water. The precipitate was filtered off and washed with water. Yield 8.8 g. The product was in the form of fine long needles of a red-brown color (from acetone) with a decomposition temperature of 234-235°. It was fairly readily soluble in pyridine, soluble with difficulty in boiling benzene and in alcohol.

0.1126 g substance: 6.95 ml N₂ (18.5°, 723 mm).

Found %: N 6.88.

C₂₂H₁₈N₂O₄S. Computed %: N 6.89.

The compound was soluble in a dilute solution (1 to 2%) of caustic soda upon gentle heating. The bluish-brown solution, upon cooling (more voluminously upon salting out) gave a precipitate of the sodium salt in the form of fine needles with a violet color. The salt was easily hydrolyzed.

The methyl-p-toluenesulfonate of 4-(anthraquinonesulfamino)-N,N-dimethylaniline (II). The compound was obtained in good yield by fusing the amine and the methyl ester of p-toluenesulfonic acid (20% excess) at 130-140°. The melt was extracted with boiling benzene, and the residue was crystallized from water and dilute alcohol. The product was in the form of pale-yellow crystals with a decomposition temperature of 238°. The addition of caustic soda, soda, or ammonia to the aqueous or aqueous alcoholic solution of the compound resulted in the formation of the betaine (III).

0.1490 g substance: 0.1169 g BaSO₄.

0.1525 g substance: 0.1195 g BaSO₄.

Found %: S 10.77, 10.76.

C₃₀H₂₈N₂O₇S₂. Computed %: S 10.82.

The methylbetaine of 4-(β-anthraquinonesulfamino)-N,N-dimethylaniline (III). 1.18 g of the methyl-p-toluenesulfonate (II) was dissolved in 15 ml of alcohol and 7 ml of water. To the hot yellow solution there was added drop by drop 2.4 ml of a 5% solution of caustic soda. Even the first drops of alkali resulted in the formation of a precipitate with a brownish-orange color (under the microscope, there were clumps of fine, needle-shaped crystals). The precipitate was filtered with suction, washed with alcohol and water, and dried for a day in a desiccator over caustic soda. Yield 0.80 g (97%). The product did not lose weight upon standing in a vacuum desiccator over phosphoric anhydride or upon being heated in a vacuum of 20 mm at 110-120°, and thus was a betaine. This was confirmed by the analytical data. The compound was insoluble in water, alcohol, acetone, benzene, chloroform, and dioxane, and dissolved with great difficulty, upon heating, in pyridine and in nitrobenzene. The melting of the product (with decomposition) took place in a manner dependent on the speed of heating, and at an initial temperature between 225 and 230°.

0.1079 g substance: 0.2595 g CO₂; 0.0471 g H₂O.

0.1882 g substance: 0.1039 g BaSO₄.

0.1729 g substance: 0.0950 g BaSO₄.

Found %: C 65.59; H 4.88; S 7.58, 7.55.

C₂₃H₂₀N₂O₄S. Computed %: C 65.70; H 4.79; S 7.63.

3-(β-Anthraquinonesulfamino)-N,N-dimethylaniline. Red-brown crystals (from alcohol) with m.p. 154-154.5°, difficultly soluble in benzene, easily soluble in acetone.

0.1494 g substance: 0.0858 g BaSO₄.

Found %: S 7.89.

C₂₂H₁₈N₂O₄S. Computed %: S 7.89.

The substance was soluble in a dilute aqueous solution of caustic soda. Upon salting out, clumps of brownish needle-shaped crystals of the sodium salt precipitated.

The methyl-p-toluenesulfonate of 3-(β-anthraquinonesulfamino)-N,N-dimethylaniline. Pale yellow crystals (from 70% alcohol) with m.p. 242-244°.

0.1716 g substance: 0.1354 g BaSO₄.

Found %: S 10.84.

C₃₀H₂₈N₂O₇S₂. Computed %: S 10.82.

The quantitative determination of sulfur in all compounds was carried out by the Carius method.

The methylbetaine of 3-(β -anthraquinonesulfamino)-N,N-dimethylaniline (IV).

This compound was obtained like the para isomer by adding dilute alkali to aqueous-alcoholic solution of the original quaternary salt. The solution acquired, during this reaction, a red-orange color, and then a crystalline precipitate of the betaine gradually came out. Yield 96%.

Red-brown needles, almost insoluble in alcohol, acetone, pyridine, and nitrobenzene. The decomposition temperature lay somewhat lower than 250° ; the results of different determinations differed sharply from each other (a discrepancy of 10° was observed).

0.2202 g substance: 0.1220 g BaSO_4 .

Found %: S 7.61.

$\text{C}_{23}\text{H}_{20}\text{N}_2\text{O}_4\text{S}$. Computed %: S 7.63.

6-(β -Anthraquinonesulfamino)-quinoline. A pale yellow, crystalline product (from pyridine) with m.p. $273-274^{\circ}$, insoluble in benzene, soluble with difficulty in alcohol, with ease in nitrobenzene.

0.1884 g substance: 0.1053 g BaSO_4 .

0.1651 g substance: 0.0920 g BaSO_4 .

Found %: S 7.68, 7.65.

$\text{C}_{23}\text{H}_{14}\text{N}_2\text{O}_4\text{S}$. Computed %: S 7.74.

The methyl-p-toluenesulfonate of 6-(β -anthraquinonesulfamino)-quinoline. Fine, lemon yellow needles (from nitrobenzene), with m.p. $258-259^{\circ}$, soluble with difficulty in water and in alcohol.

0.1410 g substance: 0.1079 g BaSO_4 .

0.1440 g substance: 0.1108 g BaSO_4 .

Found %: S 10.51, 10.57.

$\text{C}_{31}\text{H}_{24}\text{N}_2\text{O}_7\text{S}_2$. Computed %: S 10.68.

The methylbetaine of 6-(β -anthraquinonesulfamino)-quinoline (V). This compound separated out in the form of a brownish precipitate (under the microscope there were clumps of fine, needle-shaped crystals) under the action of ammonia or other weak bases (pyridine, for example) on the original quaternary salt in warm aqueous-alcoholic solution. The product which had been dried for a night over caustic alkali did not lose weight upon further standing in a vacuum desiccator over phosphoric anhydride, or even upon heating in a vacuum (20 mm) at 100° . The yield was almost quantitative. The betaine was insoluble in alcohol, chloroform, and water, soluble with difficulty in pyridine, readily soluble in boiling nitrobenzene. The decomposition temperature of the substance depended very considerably on the rate of heating, and lay around 280° .

0.2122 g substance: 0.1145 g BaSO_4 .

0.1589 g substance: 0.0844 g BaSO_4 .

Found %: S 7.41, 7.30.

$\text{C}_{24}\text{H}_{16}\text{N}_2\text{O}_4\text{S}$. Computed %: S 7.48.

The p-dimethylamino-N-benzylanilide of β -anthraquinonesulfonic acid. The anilide was formed by the interaction of N-benzyl-N',N'-dimethyl-p-phenylenediamine, obtained according to the direction of V.A. Izmailsky and B.M. Bogoslovsky [5], with the acid chloride of β -anthraquinonesulfonic acid in a solution of pyridine. Brownish-rose crystals (from benzene) with m.p. $215-216^{\circ}$, soluble with difficulty in alcohol.

0.1229 g substance: 6.20 ml N_2 (23° , 732 mm).

Found %: N 5.60.

$\text{C}_{29}\text{H}_{24}\text{N}_2\text{O}_4\text{S}$. Computed %: N 5.64.

The methyl-p-toluenesulfonate of the p-dimethylamino-N-benzylanilide of β -anthraquinonesulfonic acid (VI). Pale yellow crystals (from methanol). Upon

heating in a capillary, the substance sintered at about 210° and decomposed at about 213-215°.

0.1664 g substance: 0.1126 g BaSO₄.

0.1570 g substance: 0.1042 g BaSO₄.

Found %: S 9.29, 9.12.

C₃₇H₃₄N₂O₇S₂. Computed %: S 9.39.

When the salt was treated in methanol solution with a slight excess of alkali, there was no change in the yellow color, and no precipitate formed. Upon cooling, pale yellow crystals precipitated out of the alkaline solution. Their analysis (found 9.13% S) and their properties corresponded to those of the original quaternary salt.

SUMMARY

1. Quaternary salts of the structure (I) have been synthesized, where R is the β -anthraquinonesulfonic acid radical.

2. Under the action of alkali, these salts are readily converted into betaines. This is the result of the influence of the β -anthraquinonesulfonyl group on the NH group. The formation of the betaine (V) takes place with especial ease, as in this molecule the azene N atom is bound to the quinoline nucleus.

3. A salt of the structure (VI), which does not contain hydrogen upon the imide nitrogen, does not form a betaine under the action of alkali.

LITERATURE CITED

- [1] A.M.Simonov, J.Gen.Chem., 10, 1220 (1940); 13, 51 (1943); 19, 2208 (1949); 20, 320 (1950).*
- [2] A.M.Simonov, J.Gen.Chem. 19, 2208 (1949).***
- [3] V.A.Izmailsky, E.A.Smirnov, J.Gen.Chem. 7, 523 (1937); V.A.Izmailsky, A.V.Belotsvetov, J.Gen.Chem. 11, 700 (1941).
- [4] H.Fierz-David, Helv. chim. Acta, 10, 197 (1927).
- [5] V.A.Izmailsky, B.M.Bogoslovsky, Proc. Acad. Sci. USSR, 14, 17 (1937).

Received January 22, 1949.

* See CB translation p. a-683 ff.

** See CB translation p. 329 ff.

*** See CB translation p. a-683 ff.

AMINOALKYL ESTERS OF THIAZOCARBOXYLIC ACIDS

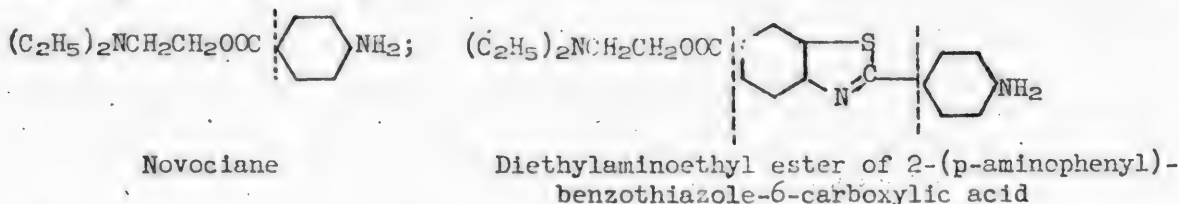
II. 2-PHENYLBENZOTHAZOLE-6-CARBOXYLIC AND 2-(p-AMINOPHENYL)-BENZOTHAZOLE-6-CARBOXYLIC ACIDS

S. G. Fridman

Institute of Organic Chemistry of the Academy of Sciences of the Ukrainian S S R.

In a previous paper there was a description of the synthesis of aminoalkyl esters of benzothiazole-2-carboxylic and benzothiazole-6-carboxylic acids [1].

It appeared to us of interest to elucidate the influence of the introduction of the benzothiazole nucleus into the molecule of aminoalkyl esters of benzoic acid on the anaesthetic properties of the latter. With this aim in mind, we synthesized the aminoalkyl esters of 2-phenylbenzothiazole-6-carboxylic and 2-(p-aminophenyl)-benzothiazole-6-carboxylic acids. The diethylaminoethyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid could be regarded as novocaine in whose molecule a benzothiazole nucleus had been introduced between the benzene ring and the ester group.



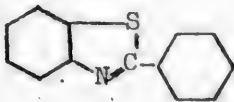
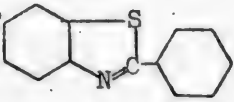
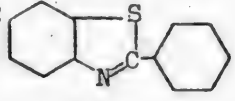
The original compound used for the synthesis of the aminoalkyl esters of the 2-phenylbenzothiazole-6-carboxylic and 2-(p-aminophenyl)-benzothiazole-6-carboxylic acids was 5-methyl-2-aminothiophenol, by whose condensation with 2-phenylbenzothiazole [2] we obtained 6-methyl-2-phenylbenzothiazole [2], which is described in the literature. By its condensation with p-nitrobenzoyl chloride we obtained 6-methyl-2-(p-nitrophenyl)-benzothiazole, which is not described in the literature.

By the oxidation of 6-methyl-2-phenylbenzothiazole with potassium permanganate in a solution of glacial acetic acid, we obtained a good yield (62% of theory) of 2-phenylbenzothiazole-6-carboxylic acid. This acid was first obtained from 6-amino-2-phenylbenzothiazole by Bogert and Abrahamson [3]. These authors, using the Sandmeyer reaction, obtained the nitrile from the amine, and saponified the nitrile to give the acid in a yield of 11% of theory based on the original amine.

The acid chloride of 2-phenylbenzothiazole-6-carboxylic acid was obtained in 95% yield by heating the acid with phosphorus pentachloride in benzene.

By the interaction of the acid chloride with β -diethylaminoethanol, γ -diethylaminopropanol, and β -piperidinoethanol, the corresponding aminoalkyl esters were obtained, as listed in Table 1.

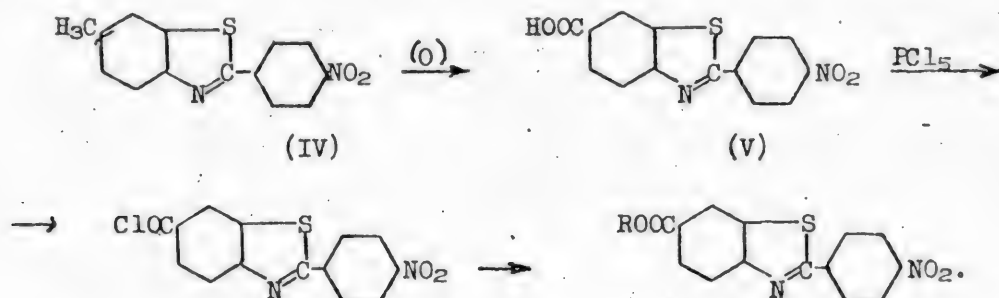
TABLE 1

Number of preparation	Structure	Melting point
I	$\text{HCl} \cdot (\text{C}_2\text{H}_5)_2\text{NCH}_2\text{-CH}_2\text{OOC}$ 	219-220°
II	$\text{HCl} \cdot (\text{C}_2\text{H}_5)_2\text{NCH}_2\text{-CH}_2\text{-CH}_2\text{OOC}$ 	205-206
III	$\text{HCl} \cdot (\text{C}_5\text{H}_{10})\text{N-CH}_2\text{-CH}_2\text{OOC}$ 	236-237

The hydrochlorides of these esters were colorless needles, barely soluble in cold water, better in hot water. They dissolved well in alcohol.

The introduction of a phenyl group in the second position of the thiazole nucleus sharply decreased the solubility in water of the hydrochlorides of the aminoalkyl esters of benzothiazole-6-carboxylic acid.

6-Methyl-2-(p-nitrophenyl)-benzothiazole (IV) was not oxidized by potassium permanganate. The compound could be oxidized by potassium dichromate in sulfuric acid solution in the presence of a small amount of dilute hydrochloric acid with a yield 70% of theory. This acid was first obtained by Schubert [4] by the condensation of the zinc salt of 5-carboxy-2-aminothiophenol with p-nitrobenzoyl chloride in a solution of pyridine. The acid was converted into the acid chloride (VI), and the interaction of the acid chloride with methanol, ethanol, β -diethylaminoethanol, γ -diethylaminopropanol, and β -piperidinoethanol gave the corresponding esters according to the equations:

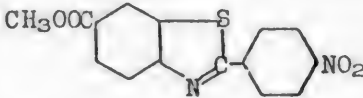
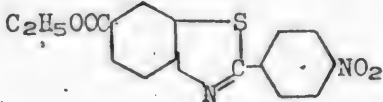
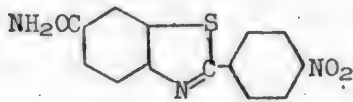
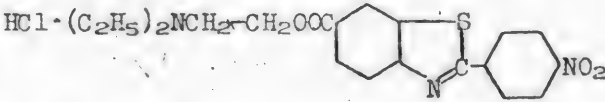
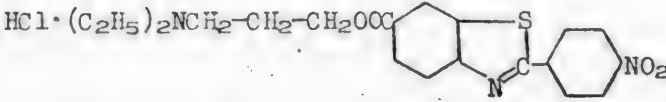
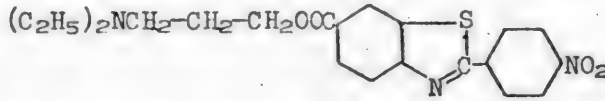
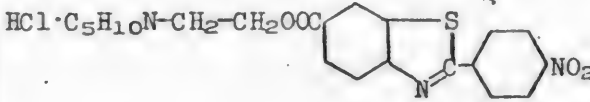


When the acid chloride (VI) was heated with an aqueous solution of ammonia, the acid amide was formed. The derivatives obtained are listed in Table 2.

The derivatives of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid obtained crystallized well in the form of small light yellow needles. The free esters, obtained by the treatment of the hydrochlorides with an aqueous solution of soda, were also crystalline compounds (for example, preparation XII). The free esters were very soluble in organic solvents and insoluble in water. The ester hydrochlorides were almost insoluble in cold water, more soluble in hot water.

By the reduction of these compounds with tin in hydrochloric acid at 40 to 50°, the corresponding amino derivatives were obtained. These are listed in Table 3.

TABLE 2

Preparation No.	Structure	Melting point
VII		259-260°
VIII		224
IX		296-297
X		238
XI		234
XII		159-160
XIII		244

The amino derivatives were in the form of yellow needles, very soluble in alcohol, acetone, benzene, chloroform, and dichloroethane, barely soluble in ether and insoluble in water.

The solutions in organic solvents had a beautiful deep blue fluorescence.

The hydrochlorides of the aminoalkyl esters of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid were obtained by the action of an alcoholic solution of hydrogen chloride on an alcoholic solution of the aminoester. They were in the form of orange crystals, well soluble in water.

Here we encountered an interesting phenomenon, the fact that the aminoalkyl esters of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid were more deeply colored than the corresponding esters of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid. A similar phenomenon was observed by Sergievskaya and Elina in the hydrochlorides of the aminoalkyl esters of β -(4-aminonaphthyl)-acrylic acid [6].

EXPERIMENTAL

1. 2-Phenyl-6-methylbenzothiazole. 33 g of 5-methyl-2-aminothiophenol, obtained from 6-methyl-2-aminobenzothiazole [1], were carefully mixed with 45 g (5% excess) of benzoyl chloride, and the mixture was heated for one hour on the boiling water bath. In order to remove the unreacted original substances, the mixture was boiled for 20 minutes with a 5% solution of caustic soda, and the

TABLE 3

Preparation No.	Structure	Melting point
XIV		218°
XV		234-235
XVI		270-271
XVII		139
XVIII		102
XIX		156

residue was washed with water, ground to a powder, and again washed with water. The dried residue was extracted several times with hot hydrochloric acid. 6-Methyl-2-phenylbenzothiazole was precipitated from the hydrochloric acid solution with water, and recrystallized from dilute alcohol. M.p. 125°; this corresponded to the data in the literature [2]. Yield 27 g (46% of theory).

2. 2-Phenylbenzothiazole-6-carboxylic acid. To a solution of 11.2 g of 6-methyl-2-phenylbenzothiazole in glacial acetic acid there was added an aqueous solution of potassium permanganate (16.5 g) and sulfuric acid (20 ml). The mixture was boiled until it became colorless, and the precipitate which formed was filtered off, washed several times with water, and dissolved in a 10% solution of caustic soda. The 2-phenylbenzothiazole-6-carboxylic acid was precipitated from the alkaline solution with dilute hydrochloric acid and recrystallized from glacial acetic acid. M p. 261°; this corresponded to the data in the literature [3]. Yield 7.8 g (62% of theory).

3. The acid chloride of 2-phenylbenzothiazole-6-carboxylic acid. To 6.8 g of the acid there was added 20 ml of chlorobenzene and 7 g of phosphorus pentachloride. The mixture was heated on the water bath for 1.5 hours, until there was complete solution of the reaction mixture. The residue, after the distillation of the chlorobenzene and the phosphorus oxychloride, was treated with a solution of sodium bicarbonate, dried, and recrystallized from solution. It was in the form of light-yellow needles. After several recrystallizations from benzene, the compound had m.p. 177° (according to the patent data [5], it is 195-196°). The yield was 6.9 g (95% of theory). From the acid chloride, the methyl ester was obtained, with m.p. 159° (according to data in the literature, it is 153-154° [3]).

4. The β -diethylaminoethyl ester of 2-phenylbenzothiazole-6-carboxylic acid.

To a solution of 1 g of the acid chloride of 2-phenylbenzothiazole-6-carboxylic acid in benzene there was added 0.43 g of diethylaminoethanol, and the reaction mixture was heated for 2 hours on the boiling water bath. The white precipitate of the hydrochloride of the diethylaminoethyl ester of 2-phenylbenzothiazole-6-carboxylic acid which formed was filtered off, washed with hot benzene, and recrystallized from dichloroethane. M.p. 219-220°. Yield 1.22 g (78% of theory). It was very soluble in alcohol, slightly soluble in cold water.

Found %: N 7.23.*

$C_{20}H_{22}O_2N_2S \cdot HCl$. Computed %: N 7.17.

Determination of ionic chlorine, according to Volhard:

Found %: Cl 9.15.

$C_{20}H_{22}O_2N_2S \cdot HCl$. Computed %: Cl 9.09.

The picrate was obtained from equimolecular quantities of the ester hydrochloride and picric acid. It was recrystallized from acetone. M.p. 169°.

Found %: N 11.83.

$C_{28}H_{25}O_9N_5S$. Computed %: N 12.00.

5. The γ -diethylaminopropyl ester of 2-phenylbenzothiazole-6-carboxylic acid (II). This was obtained from 1 g of the acid chloride and 0.5 g of diethylaminopropanol in benzene, like the preceding compound. The preparation was recrystallized from dichloroethane: it had m.p. 205-206°. The yield was 1 g (75% of theory). It was very soluble in alcohol, slightly soluble in cold water.

Found %: N 6.74.

$C_{21}H_{25}O_2N_2SCl$. Computed %: N 6.92.

Determination of ionic chlorine, according to Volhard:

Found %: Cl 8.92.

$C_{21}H_{24}O_2N_2SCl$. Computed %: Cl 8.77.

The picrate was obtained in the same way as the preceding picrate. M.p. 157°.

Found %: N 11.85.

$C_{27}H_{27}O_9N_5S$. Computed %: N 11.72.

6. The β -piperidinoethyl ester of 2-phenylbenzothiazole-6-carboxylic acid (III). This was obtained in the same way as the preceding compound from 1 g of the acid chloride and 0.5 g of β -piperidinoethanol in benzene. After recrystallization from dichloroethane, it had m.p. 236-237°. The yield was 1.1 g (78% of theory). It was very soluble in alcohol, slightly soluble in cold water.

Found %: N 6.75.

$C_{21}H_{23}O_2N_2SCl$. Computed %: N 6.95.

Determination of ionic chlorine according to Volhard:

Found %: Cl 8.60.

$C_{21}H_{22}O_2N_2S \cdot HCl$. Computed %: Cl 8.81.

7. 6-Methyl-2-(p-nitrophenyl)-benzothiazole (IV). 20 g of methyl-2-aminothiophenol was carefully ground up with 38 g (10% excess) of p-nitrobenzoyl chloride, and the mixture was heated on the water bath for one hour. The reaction mixture was boiled with a 5% solution of alkali, and the residue washed several times with water. After it was recrystallized several times from glacial acetic acid and then from dichloroethane, the compound had m.p. 219°. The yield was 22 g (52% of theory). It was soluble in glacial acetic acid, dichloroethane, and benzene, and insoluble in water.

Found %: N 10.42.

$C_{14}H_{10}O_2N_2S$. Computed %: N 10.37.

Nitrogen microanalysis according to Dumas.

8. 2-(p-Nitrophenyl)-benzothiazole-6-carboxylic acid (V). To a solution of 12.5 g of 6-methyl-2-(p-nitrophenyl)-benzothiazole in 100 ml of 70% sulfuric acid, there was added 0.5 ml of hydrochloric acid (sp. gr. 1.12). During careful heating on the water bath, there were sprinkled in, in portions, 15 g of powdered potassium dichromate. After the addition of the entire quantity of dichromate, the reaction mixture was heated for 15 minutes on the boiling water bath. After cooling, the mixture was diluted with 200 ml of water, and the precipitate filtered off, washed several times with water, and then, while being heated on the water bath, suspended in 200 ml of a 5% solution of sulfuric acid in order to remove salts of chromium. After cooling, the precipitate was filtered off, washed with water, dissolved in a 1% solution of caustic soda, and filtered off from the small amount of unreacted thiazole. When the filtrate was cooled, the sodium salt of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid precipitated out. This was recrystallized once more from hot water. The acid was obtained by acidifying the solution with dilute hydrochloric acid and was recrystallized from glacial acetic acid. It was in the form of fine colorless needles with m.p. 320°. Yield of sodium salt 9.9 g (67% of theory).

Found %: N 8.39.

$C_{14}H_7O_4N_2SNa$. Computed %: N 8.69.

Determination of percentage of sodium by combustion with sulfuric acid.

Found %: Na 6.8, 7.01.

$C_{14}H_7O_4N_2SNa$. Computed %: Na 7.11.

Schubert [4] first obtained this acid by condensing the zinc salt of 5-carboxy-2-aminothiophenol with p-nitrobenzoyl chloride. However, in his work, the author did not give any analytical data or the melting point of the acid he had obtained.

9. The acid chloride of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (VI). This was obtained from 7 g of the acid and 5 g of phosphorus pentachloride by heating in chlorobenzene, and was recrystallized from benzene. M.p. 206°. (According to Schubert, the m.p. is 205°). Yield 7.2 g (97% of theory).

10. The methyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (VII). This compound was obtained by boiling the acid chloride with methyl alcohol on the water bath for one hour. The precipitate was washed with a solution of sodium bicarbonate and with water, and recrystallized from benzene. M.p. 259-260°. Yield 91% of theory. Soluble in hot benzene, almost insoluble in alcohol and insoluble in water.

Found %: N 8.94.

$C_{15}H_{10}O_4N_2S$. Computed %: N 8.91.

11. The ethyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (VIII). This was obtained by boiling the acid chloride with ethyl alcohol in the same way as the preceding compound. It was recrystallized from benzene. Light-yellow needles with m.p. 224°. Soluble in benzene, almost insoluble in methyl and ethyl alcohols, insoluble in water.

Found %: N 8.71.

$C_{16}H_{12}O_4N_2S$. Computed %: N 8.53.

12. The amide of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (IX). This was obtained by boiling the acid chloride with an aqueous solution of ammonia on the water bath for 30 minutes. It was recrystallized from glacial acetic acid as light yellow needles with m.p. 296-297°. It was insoluble in benzene, methyl or ethyl alcohol, or water, very soluble in glacial acetic acid.

Found %: N 13.83.

$C_{14}H_9O_3N_3S$. Computed %: N 14.04.

13. The β -diethylaminoethyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (X) was obtained by heating 1 g of the acid chloride of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid and 0.36 g of diethylaminoethanol in benzene on the water bath for an hour. The precipitate was recrystallized from alcohol. Light yellow needles with m.p. 238° (with decomposition). Yield 1.1 g (85% of theory). Very soluble in alcohol, slightly soluble in water.

Found %: N 9.67.

$C_{20}H_{22}O_4N_3SCl$. Computed %: N 9.64.

14. The hydrochloride of the γ -diethylaminopropyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (XI) was obtained from the acid chloride (1 g) and of the diethylaminopropanol (0.41 g) in benzene, in the same way as the preceding compound. It was recrystallized from alcohol. Light yellow needles with m.p. 234° (with decomposition). Yield 1.2 g (86% of theory). Very soluble in alcohol, slightly soluble in water.

Found %: N 9.28.

$C_{21}H_{24}O_4N_3SCl$. Computed %: N 9.34.

15. The γ -diethylaminopropyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (XII) was obtained from the hydrochloride of the diethylaminopropyl ester (XI) by treatment with sodium carbonate. It was recrystallized from alcohol. Light yellow needles with m.p. $159-160^\circ$. Insoluble in water, very soluble in alcohol, benzene, acetone, and chloroform.

Found %: N 9.96.

$C_{21}H_{23}O_4N_3S$. Computed %: N 10.16.

16. The β -piperidinoethyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (XIII) was obtained from the acid chloride (1 g) and β -piperidinoethanol (0.41 g) in benzene, in a manner similar to the preceding compounds. It was recrystallized from alcohol. Light yellow needles with m.p. 244° . Yield 1.2 g (86% of theory). Soluble in alcohol, slightly soluble in water.

Found %: N 9.23.

$C_{21}H_{22}O_4N_3SCl$. Computed %: N 9.35.

17. The methyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid (XIV) was obtained by heating on the water bath at $40-45^\circ$ a mixture of 1 g of the methyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (VII) and 2 g of metallic tin in 10 ml of hydrochloric acid, until the nitroester had completely dissolved. Upon cooling, there precipitated out after some time the double salt of the aminoester with stannous chloride. This was filtered off and decomposed with a 10% solution of caustic soda in the cold. The precipitate which formed was filtered off, washed with a dilute solution of caustic soda and with water, and recrystallized from dilute alcohol. Yellow needles were obtained, with m.p. 218° . Yield 0.45 g (50% of theory). It was very soluble in alcohol, benzene, acetone, and chloroform, slightly soluble in ether, and insoluble in water. The solutions had a beautiful deep-blue fluorescence.

Found %: N 9.97.

$C_{15}H_{12}O_2N_2S$. Computed %: N 9.85

18. The ethyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid (XV) was obtained from 1 g of the ethyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (VIII), in a manner similar to the preceding compound. Yellow needles with m.p. $234-235^\circ$. Yield 0.4 g (44% of theory). Solutions had a deep blue fluorescence.

Found %: N 9.39.

$C_{16}H_{14}O_2N_2S$. Computed %: N 9.23.

19. The amide of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid (XVI).

The compound was obtained from the amide of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (IX) by reduction with tin and hydrochloric acid. It was recrystallized twice from very dilute alcohol. Yellow needles with m.p. 270-271°. Yield 38% of theory. Soluble in alcohol, benzene, chloroform, and acetone, not so soluble in ether, insoluble in water. Solutions had an intense deep-blue fluorescence.

Found %: N 15.62.

$C_{14}H_{11}ON_3S$. Computed %: N 15.61.

20. The β -diethylaminoethyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid (XVII).

This was obtained by heating 1 g of the hydrochloride of the diethylaminoethyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (X) with tin in hydrochloric acid. The precipitate was recrystallized from aqueous alcohol. Yellow crystals with m.p. 139°. Yield 0.34 g (41% of theory). Very soluble in alcohol, acetone, benzene, chloroform, and dichloroethane, slightly soluble in ether, and insoluble in water. Solutions had a splendid deep-blue fluorescence.

Found %: N 11.17.

$C_{20}H_{23}O_2N_3S$. Computed %: N 11.35.

The hydrochloride of the ester was formed by pouring an alcoholic solution of hydrogen chloride into an alcoholic solution of the ester. Orange crystals precipitated, very soluble in water.

21. The γ -diethylaminopropyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid (XVIII).

was obtained from 1 g of the hydrochloride of the diethylaminopropyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (XI) in a similar manner. It was recrystallized from very dilute aqueous alcohol. Yellow needles with m.p. 102°. Yield 0.36 g (45% of theory). It dissolved in alcohol, acetone, chloroform, and benzene, giving fluorescent solutions.

Found %: N 10.69.

$C_{21}H_{25}O_2N_3S$. Computed %: N 10.96.

The picrate of the diethylaminopropyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid was recrystallized from acetone in the form of orange needles with m.p. 198°.

Found %: N 13.72.

$C_{27}H_{28}O_6N_6S$. Computed %: N 13.56.

22. The β -piperidinoethyl ester of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid (XIX).

was obtained from 1 g of the β -piperidinoethyl ester of 2-(p-nitrophenyl)-benzothiazole-6-carboxylic acid (XII) in a similar manner. Yellow needles with m.p. 156°. Yield 0.35 g (45% of theory). Solutions had a deep blue fluorescence.

Found %: N 10.76.

$C_{21}H_{23}O_2N_3S$. Computed %: N 11.02.

The author is deeply appreciative of the valuable guidance of Prof. A.I. Kiprianov in this work.

SUMMARY

In order to explain the influence of the introduction of the benzothiazole nucleus into the molecules of aminoalkyl esters of benzoic and p-aminobenzoic acids on their anaesthetic action, we synthesized the β -diethylaminoethyl, γ -diethylaminopropyl, and β -piperidinoethyl esters of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid. In passing, we obtained the methyl and ethyl esters and the amide of 2-(p-aminophenyl)-benzothiazole-6-carboxylic acid.

LITERATURE CITED

- [1] S.G.Fridman, J.Gen.Chem. 20, 1191 (1950).*
- [2] Hess, Ber., 14, 493 (1881); Pflizinger, Gatterman, Ber., 22, 1065 (1899).
- [3] M.Bogert, Abrahamson, J.Am.Chem.Soc., 44, 836 (1922).
- [4] Schubert, Ann., 558, 11 (1947).
- [5] Zerweck, I.G.Kunze, German patent 602,336; Frdl., 21, 1088.
- [6] S.I.Sergievskaya and A.S.Elina, J.Gen.Chem. 13, 870 (1943).

Received December 5, 1948.

* See SB translation p. 1235 ff.

THE PREPARATION OF ACENAPHTHYLENE

B. M. Mikhailov and A. N. Blokhina

Institute of Organic Chemistry of the Academy of Sciences of the USSR

The simplest methods of obtaining acenaphthylene (II) consist of passing the vapors of acenaphthene (I) through a glowing glass tube which contains lead oxide [1,2], or a quartz tube, empty [3] or filled with iron or copper wire [4].

In all the works cited, the authors fail to mention the exact temperature at which the process takes place. They limit themselves only to the direction that the reaction tube be heated to red heat. N.N.Efremov in a paper on the thermal analysis of hydrocarbon picrates [5] attempted to give the exact temperature conditions for the preparation of acenaphthylene by passing the vapors of



acenaphthene over glowing lead oxide. According to his data, the optimal temperature is 450-475°; at this temperature the transformation of acenaphthene into acenaphthylene takes place to the extent of 90 to 95%. The material he obtained was in the form of beautiful clear yellow crystals with m.p. 91°, sharply differing in color from the original colorless acenaphthene (m.p. 95.2°). The melting point of the picrate of the hydrocarbon he had obtained was, however, considerable lower (165.3°) than that indicated in the literature for the picrate of acenaphthylene (201-202°).

In order to obtain acenaphthylene, which we needed in the course of our work, we utilized the directions of Efremov and passed acenaphthene vapors through a tube with lead oxide, heated to 450-475°. The substance which we obtained in good yield was in the form, after recrystallization from alcohol, of needles with a clear yellow color, with m.p. 90-92°. The crystal form (needles, instead of the tablets characteristic of acenaphthylene) and a measurement of the solubility in alcohol of the substance we had obtained, aroused some doubt in us, however, as to whether this was acenaphthylene. In fact, the substance obtained was not acenaphthylene, but the original acenaphthene, colored a clear yellow by some impurity from which it could not be freed by crystallization. A mixed test of the compound obtained with a sample of acenaphthene gave no depression of the melting point (92-94°); its picrate had m.p. 161-162°, and showed no depression of the melting point in a mixed test with the picrate of acenaphthene (161-162°). Additional experiments that we made for the sake of comparison showed that the optimal temperature for the preparation of acenaphthylene was 640-660°. On passing the vapors of acenaphthene through lead oxide heated to this temperature, acenaphthylene (m.p. 92-93°, picrate with m.p. 202-203°) was obtained in a yield of

about 30%, based on the acenaphthene used in the reaction.

EXPERIMENTAL

A small Wurtz flask, fitted with a glass tube which led to the bottom, was joined to a quartz tube (filled with lead oxide) which was placed in an electric oven (length 40 cm). The end of the tube was fitted with a receiver. The acenaphthene was placed in the flask and heated on a Wood bath (320-330°), and a current of nitrogen was passed through the boiling hydrocarbon, extracting the vapors of the hydrocarbon into the reaction tube.

In an experiment carried out at a temperature of 450-475° (thermocouple), 6 g of acenaphthene gave 5 g of a substance colored clear yellow, with m.p. 87-92°. After recrystallization from alcohol, the substance was in the form of needles with a yellow color (m.p. 90-92°), and gave no depression of the melting point with a sample of acenaphthene. The picrate of the substance obtained had m.p. 161-162°; a mixed test with the picrate of acenaphthene gave m.p. 161-162°.

In an experiment carried out at 640-660°, 5.7 g of acenaphthene gave 4.5 g of a mixture of hydrocarbons, which was fractionated by the crystallization of the picrates from benzene. 1.74 g (30.5%) of acenaphthylene was obtained with m.p. 92-93° (the picrate had m.p. 202-203°) and 0.1 g of acenaphthene.

SUMMARY

1. By passing acenaphthene over lead oxide heated to 450-475°, Efremov obtained the original hydrocarbon, and not acenaphthylene.
2. The optimal temperature for the preparation of acenaphthylene from acenaphthene by means of heated lead oxide is the range 640-660°.

LITERATURE CITED

- [1] A.Behr and W.Dorp, Ber., 6, 753 (1873).
- [2] M.Blumenthal, Ber., 7, 1092 (1874).
- [3] K.Dziewonski and G.Rapalski, Ber., 45, 2491 (1912).
- [4] K.Dziewonski, Ber., 53, 2173 (1920).
- [5] N.N.Efremov, J.Russ.Chem.Soc., 50, 398 (1920).

Received February 11, 1949.

STUDIES IN SULFONATION

XIV. THE PREPARATION OF SULFONYL CHLORIDES FROM THE SODIUM SALTS OF SULFONIC ACIDS

A. A. Spriskov and N. V. Aparyeva

Ivanov Chemical-Technological Institute and Ivanov State Medical Institute

The acid chlorides of sulfonic acids of the aromatic series are obtained either by the sulfonation with chlorosulfonic acid of compounds which do not contain sulfonyl groups or by the action of the chlorides of phosphorus on the sodium and potassium salts of the sulfonic acids. However, it is also possible to obtain the chlorides from the alkaline salts by treating them with chlorosulfonic acid. The latter method, to be sure, is very seldom used, as it has not been well developed and has been very briefly described in the chemical literature. None the less the use of chlorosulfonic acid for transforming the salts of sulfonic acids into the acid chlorides has the following advantages over the use of phosphorus pentachloride: 1) the accessibility of chlorosulfonic acid in comparison with that of phosphorus pentachloride, 2) its low stability, 3) the considerably lower degree of toxicity for those working with it, in comparison with the phosphorus chlorides, and 4) the process of formation and separation of the sulfonyl chloride in many cases takes place more rapidly and more simply than with phosphorus pentachloride (there is no need of the frequently recommended distillation of phosphorus hydroxychloride from the reaction mixture).

We have previously [1] described the preparation of the acid chloride of 1,5-naphthalenedisulfonic acid from its sodium salt by the action of chlorosulfonic acid under various conditions (temperature, duration of reaction, ratio of reagents, etc.). We have also given a brief review of the far from extensive literature which refers to this question. In the present paper it is our purpose to show that the transformation of the sodium salts of sulfonic acids is possible with good yields of different sulfonyl derivatives. We investigated the transformation into the chloride of the sodium salts of mono-, di-, and trisulfonic acids of the benzene and naphthalene series, both without substituents and also with different substituents in the nucleus (Cl, CH₃, COOH, OH, NO₂).

The preparation of benzenesulfonyl chloride. The possibility of forming the sulfonyl chloride from the sodium salt of benzenesulfonic acid was demonstrated in 1882 by Heumann and Köchlin [2], who did not describe the conditions of formation or the yield of product. V.M. Rodionov [3] described the conditions for the formation of benzenesulfonyl chloride from the sodium sulfonate and chlorosulfonic acid with a yield of about 65%. In the preparation of benzenesulfonyl chloride by the action of phosphorus pentachloride on the sodium sulfonate or of chlorosulfonic acid on benzene, the yield reached about 75-80% of theory [4]. In these cases, the chloride was extracted with carbon tetrachloride and distilled in vacuum.

Our experiments were carried out in the following manner. To the pure sodium

salt of benzenesulfonic acid, dried at a temperature of about 200°, chlorosulfonic acid* was added, and the mixture was kept at a definite temperature. The reaction mass was poured, with vigorous stirring, on ice which had been seeded with a small crystal of the benzenesulfonyl chloride. In this process, the chloride precipitated out in crystalline form, and was filtered with suction on a funnel which was externally cooled with ice. After washing with ice water, the chloride was dried in a desiccator for 1 or 2 days over pieces of caustic soda at a temperature which did not exceed 10°. Finally, the chloride was dried in vacuum at a pressure of 5 to 15 mm, its loss in weight after 2 to 4 hours not exceeding 0.01 g. Its melting point was then determined.

TABLE 1

The formation of benzenesulfonyl chloride by the action of 4 ml of chlorosulfonic acid on 2 g of the sodium salt of benzenesulfonic acid

Experiment No.	Temperature	Duration, hours	Yield of chloride (% of theory)	Melting point of the chloride obtained
27	10°	24	85.5	15.5°
101	16	2	86.0	15.5-16
33	85	2	88.0	14.5-15
31	85	2	94.8	13.5
51	85	2	96.5	12-13.5
50	100	1	89.9	14-15
37	100	2	96.5	11

The results of the experiments listed in Table 1 show that by this method it was possible to obtain a chloride of excellent quality in yields above 90% of theory. The reaction is best carried out at a temperature not exceeding 85°. The yield can reach 95-96% (Experiments 37, 51), but the quality of the product at this yield is lower. This is the result of the insufficiently careful washing of the chloride on filtration. Careful washing itself results in losses as a result of the solubility and hydrolysis of the chloride in water. We confirmed this fact by the following experiment. To 200 ml of water at a temperature of 0-1° we added about 1 g of the crystalline chloride, and stirred the mixture continuously. We periodically withdrew 25 ml of the liquid, quickly filtered it, and titrated it with 0.1 N alkali. The same filtered sample was titrated after heating to 95-100°, in order to hydrolyze the dissolved chloride. The results of the experiments, listed in Table 2, show that the chloride is very slightly soluble in water, but that once it is dissolved it is hydrolyzed, and that therefore the process of solution takes place continuously. Of all the chloride dissolved, about 80 to 85% is hydrolyzed in the cold, and 15 to 20% remains in solution unhydrolyzed.

Thus, the method described gives a high yield of chloride in the form of a pure crystalline product with a melting point close to the melting point of the individual substance, and it does not require either extraction with solvents or the usual application of distillation in vacuum.

The benzenesulfonyl chloride obtained, after recrystallization from ligroin and then from petroleum ether, was in the form of completely white crystals with m.p. 16.3°.

The preparation of p-toluenesulfonyl chloride. By the action of chlorosulfonic acid on the sodium salt of p-toluenesulfonic acid, V.M. Rodionov [3] obtained p-toluenesulfonyl chloride, but he did not indicate the yield of product.

For our experiments, we used the sodium salt of p-toluenesulfonic acid obtained from p-toluenesulfonyl chloride with m.p. 69°. The salt was mixed with

*The chlorosulfonic acid used was distilled in vacuum (see experimental part).

chlorosulfonic acid, the mixture kept at a definite temperature, and then poured on ice. The chloride was filtered off, washed and dried over solid caustic soda to constant weight.

The results of the experiments, as listed in Table 3, show that it is best to carry out the preparation of the chloride at a temperature below room temperature. At 0°, the pure chloride is obtained in a yield 92% of theory.

The higher the temperature and the duration of the interaction of the components, the worse the quality of the product, despite careful washing. We are inclined to explain this by the formation of a slight amount of toluenedisulfonyl chloride.

TABLE 2

The solution and hydrolysis of benzene-sulfonyl chloride

By titration	Computed chloride content in entire solution (in g) after		
	2 hours	3 hours	4 hours
Of the cold solution ...	0.065	0.097	0.108
After heating	0.081	0.115	0.133
Difference...	0.016	0.018	0.025

TABLE 3

The preparation of p-toluenesulfonyl chloride by the action of 2 ml of chlorosulfonic acid on 1 g of the sodium salt of p-toluenesulfonic acid

Experiment No.	Temperature	Duration, hours	Yield of chloride (% of theory)	Melting point of the chloride obtained
102	0°	2	91.8	68°
99	16	2	92.6	65
90	16	2	94.0	64
95	16	24	90.6	59
89	100	2	78.0	46

The preparation of 2-chlorotoluene-4-sulfonyl chloride. 2-Chlorotoluene-4-sulfonyl chloride had previously been obtained from the potassium salt of 2-chlorotoluenesulfonic acid and phosphorus chloride in the form of a non-crystallizing oil [5]. The chloride was later obtained by the chlorination of p-toluenesulfonyl chloride [6].

In our experiments, the technical sodium salt of 2-chlorotoluenesulfonic acid was recrystallized from 1 to 3 times from water, dried at 130-150°, mixed with chlorosulfonic acid, and the mixture kept at a definite temperature. Then the same procedure was followed as for p-toluenesulfonyl chloride. The results of the experiments, as listed in Table 4, show that this chloride was also obtained with extraordinary ease and in high yields.

In Experiment 68, chlorosulfonic acid was added rapidly to the salt. As a result of the reaction, the temperature rose in 1 minute to 44°, and the mixture was immediately poured on ice. Even in this experiment, 40% of chloride was formed. We were unable to obtain a yield above 97.5% even by the action of 12 ml of chlorosulfonic acid on 2 g of the salt at 100°. It is possible that part of the chloride was hydrolyzed during the washing.

According to the data in the literature, the melting point of 2-chlorotoluene-4-sulfonyl chloride is 38° [8]. However, we were unable to obtain a chloride with a melting point about 35°, despite the fact that we recrystallized the salt 1, 2, and 3 times. The results obtained are in general identical. But the amide, obtained by the action of a 20% solution of ammonia on the chloride with m.p. 35°, without recrystallization had m.p. 134.5° (according to the literature, it is 135°). After five recrystallizations from ether, the melting point of the chloride remained equal to 35°.

TABLE 4

The preparation of 2-chlorotoluene-4-sulfonyl chloride by the action of 4 ml of chlorosulfonic acid on 2 g of the sodium salt of 2-chlorotoluene-4-sulfonic acid

Experiment No.	Temperature	Duration	Yield of chloride (% of theory)	M.p. of chloride obtained	Technical salt of sulfonic acid re-crystallized
68	20-44°	1 min.	40.0	34°	2 times
70	25	10 min.	63.6	35	3 times
56	25	2 hours	93.2	35	1 time
60	15	20 hours	97.6	33	1 time
59	65	2 hours	94.2	34	3 times
57	85	2 hours	96.4	32	1 time
58	100	2 hours	97.5	35	1 time
71	126	2 hours	93.5	32	3 times

The preparation of the acid chloride of sulfosalicylic acid. The acid chloride of sulfosalicylic acid had previously been obtained only by the action of chlorosulfonic acid on salicylic acid in a yield of about 60% [7]. It was found that if the sulfonate was rapidly added to the chlorosulfonic acid without cooling, a slight degree of heating took place, along with the evolution of a large amount of hydrogen chloride. This evolution of gas indicated that sulfonation was taking place, as the entrance of a second sulfonyl group proceeded very readily. In such experiments, the yield of chloride was very low. After dissolving the salt in acid, the reaction could be carried out at a temperature from 18 to 65°. It was found later that the chloride was appreciably soluble in water, and was hydrolyzed; therefore, its washing on the filter, and its drying as well, required care.

After a number of experiments, we obtained the chloride in the following manner. To the chlorosulfonic acid, cooled to 5-7°, we gradually added the salt

TABLE 5

The preparation of the sulfonyl chloride of sulfosalicylic acid from 4 g of its sodium salt

Experiment No.	SO ₃ HCl used, ml	Temperature	Duration, hours	Yield of chloride in % of theory	M.p. of chloride obtained
18	10	14°	24	71.2	172°
19	20	14	24	86.4	160
13	20	22	24	81.8	160
21	10	63	1	81.2	167
23	20	63	1	86.0	165

of sulfosalicylic acid, dried at 190-200°, while the vessel was continually cooled with cold water. This was continued for about 10 minutes, and during this time, no evolution of gas took place. Then the mixture was kept at the same temperature until there was complete solution, with periodic shaking, and after that it was kept at room temperature or heated. The reaction mixture was poured upon three times its weight of ice, and the precipitate was rapidly filtered with suction in a funnel cooled with ice, washed 5 times with 5 ml portions of ice water (for 3 to 3.5 g of chloride) and dried in a desiccator over solid caustic potash at room temperature. The results of the experiments carried out, as listed in Table 5, show that at a yield of 70% of theory, a chemically pure product was obtained

(the melting point of the individual substance was 171-172°) [8]. The yield of a product of somewhat inferior quality, with m.p. 165°, amounted to 85%. This was the result of an insufficiently thorough washing of the chloride on the filter; careful washing resulted in a considerable loss as a result of the solubility and hydrolysis of the chloride in water.

The extent of the loss could be evaluated from the following experiment. 1 g of the chloride with m.p. 172° was stirred with 40 ml of water or 36% hydrochloric acid for 20 minutes. The residue was then quickly filtered off, and the filtrate was titrated with 0.1 N alkali solution and silver nitrate, using Volhard's method. We thus found: in water at 0°, 0.06 g was dissolved and hydrolyzed, at 25°, 0.53 g; in 36% hydrochloric acid (from the chloride residue on the filter) at 1°, 0.03 g, and at 18°, 0.07 g. The process of solution of the chloride thus took place more slowly in hydrochloric acid. We did not find any unhydrolyzed chloride in the solution, in the way we were able to find it for benzenesulfonyl chloride. After solution, the chloride was apparently hydrolyzed very rapidly. From the results of the titration with alkali and silver nitrate, the chloride contains no chlorine in the carboxyl group.

In Experiments 13 and 16, the chloride was washed on the funnel with 36% hydrochloric acid; however, this chloride dried more slowly, and this lowered the quality of the product, and we therefore stopped washing with hydrochloric acid.

The production of α - and β -naphthalenesulfonyl chlorides. α -Naphthalenesulfonyl chloride has been obtained up to the present time by the action of chlorosulfonic acid on naphthalene in a solvent [9] or by the action of phosphorus pentachloride on alkali salts of the sulfonic acid [10].

We mixed the sodium salt of α -naphthalenesulfonic acid with chlorosulfonic acid at room temperature, and found that at this temperature, sulfonation took place with the formation of disulfonyl derivatives. The monosulfonyl chloride could be obtained only by carefully adding the salt to the chlorosulfonic acid at a temperature from 12 to 15°. The solution of the salt, however, took place very slowly. After 2 hours of stirring, the salt was still not completely dissolved. The mixture was poured on ice, and the chloride was obtained from it in a yield 40% of theory, and with m.p. 66°.

β -Naphthalenesulfonyl chloride could not be obtained by the action of chlorosulfonic acid on the sodium salt of β -naphthalenesulfonic acid, as even at a temperature of -10° a mixture of the disulfonyl chlorides with a melting range from 98 to 115° was formed.

The preparation of m-nitrobenzenesulfonyl chloride. m-Nitrobenzenesulfonyl chloride had previously been obtained from the sulfonic acid and phosphorus pentachloride [11], from nitrobenzene and chlorosulfonic acid [12], and by other methods, but it had not been obtained from salts of the sulfonic acid and chlorosulfonic acid.

The results of our experiments on the preparation of m-nitrobenzenesulfonyl chloride by the action of chlorosulfonic acid on the sodium salt of m-nitrobenzenesulfonic acid are given in Table 6.

This chloride was far from being obtained as easily as all the chlorides of the benzene series described above. In order to obtain a high yield, it was necessary to raise the temperature or increase the duration of the reaction at room temperature. However, the chloride was obtained very pure, and in a yield up to 93% of theory.

The preparation of m-benzene-disulfonyl chloride. m-Benzenedisulfonyl chloride had previously been obtained either by the action of phosphorus pentachloride on the sodium salt of benzenedisulfonic acid [13] or by the action of a 10-fold

amount of chlorosulfonic acid on benzene [14]. Using the latter method, we obtained the dichloride with a melting point of 60°, and we converted this into the sodium salt of the disulfonic acid. In order to obtain the dichloride from the salt, the latter was mixed with chlorosulfonic acid, kept at a definite temperature, and the mixture poured on ice. The results of the experiments, listed in Table 7, show that the salt of benzenedisulfonic acid is converted into the chloride with more difficulty than all the other salts of sulfonic acids tested by us.

Thus, for example, all the other salts of sulfonic acids, on reacting with chlorosulfonic acid at room temperature, gave a considerable yield of chloride, while the salt of benzenedisulfonic acid under these conditions is almost unchanged.

At higher temperatures, too, the reaction takes place more slowly than with other salts (see, for example, the results at 65°). When the temperature is raised above 85°, the yield of chloride is decreased. Apparently, at 85°, a condition is reached which is close to equilibrium, and at still higher temperatures this is shifted back, as a result of a positive heat effect of the reaction. With a large excess of chlorosulfonic acid, the yield of chloride reaches 88%.

TABLE 6

The preparation of m-nitrobenzenesulfonyl chloride by the action of 2 ml of chlorosulfonic acid on 1 g of the sodium salt of m-nitrobenzenesulfonic acid.

Expt. No.	Temperature	Duration, hours	Yield of chloride (% of theory)	Melting point of the chloride obtained
97	15°	2	54.2	62°
92	15	68	67.8	63
98	85	2	93.2	63

TABLE 7

The preparation of m-benzenedisulfonyl chloride from the sodium salt of m-benzenedisulfonic acid

Experiment No.	SO ₃ HCl used per 1 g of salt (ml)	Temperature	Duration, hours	Yield of chloride, in % of theory	Melting point of chloride obtained
67	2	20°	120	Traces	-
63	2	29	2	0	-
73	2	65	6	46.2	60°
61	2	85	2	63.8	59
62	2	100	2	61.8	59
65	2	114	2	58.2	58
75	2	139	2	57.3	60
76	6	100	2	87.8	59

The preparation of 1,3,5-naphthalenetrisulfonyl chloride. The acid chloride of 1,3,5-naphthalenetrisulfonic acid had previously been obtained only by the action of phosphorus pentachloride on the salt of the trisulfonic acid [15]. The pure sodium salt of the acid was obtained from its sulfonyl chloride with m.p. 146°. The results of the experiments on the transformation of the salt into chloride by the action of chlorosulfonic acid are presented in Table 8. They show that the pure salt gives a pure chloride in a yield about 85% of theory. The high degree of purity of the chloride is attained as a result of voluminous washing with water during filtration. The chloride is hydrolyzed very slowly at room temperature.

Thus, we investigated the transformation into sulfonyl chlorides by the use of chlorosulfonic acid of 8 different sodium sulfonates, chiefly with different substituents in the nucleus.

The results of the experiments carried out show that the sulfonyl chlorides are more easily obtained from the salts of those sulfonic acids which do not have other substituents in the nucleus, or have substituents of the first kind (benzene sulfonic acid; toluenesulfonic acid, chlorotoluenesulfonic acid, salicylic acid, α -naphthalenesulfonic acid). Salts of sulfonic acids which have groups of the second kind in the nucleus are converted into chlorides with much greater difficulty (di- and trisulfonic acids of naphthalene, benzenedisulfonic acid, nitrobenzenesulfonic acid). Thus, the salts of those sulfonic acids which are more easily formed during the processes of sulfonation are more easily converted into sulfonyl chlorides, and vice versa. For example, benzenedisulfonic acid is obtained by the sulfonation of the monosulfonic acid only at very high temperature ($250-270^\circ$), and its chloride is formed with more difficulty than all the other chlorides obtained.

TABLE 8

The preparation of 1,3,5-naphthalenetrisulfonyl chloride (6 ml of chlorosulfonic acid used per 1 g of the sodium salt of the acid).

Expt. No.	Temperature	Duration, hours	Yield of chloride, % of theory	M.p. of the chloride obtained
84	20°	120	74.2	145°
82	100	2	83.8	145
3	140	2	86.0	144

EXPERIMENTAL

In all cases we used chlorosulfonic acid which had been distilled at ordinary pressure or in vacuum. Using distillation at ordinary pressure, we chose the fractions from 146 to 150° and from 150 to 152° . Thus, the acid was not the same in all experiments. The chlorosulfonic acid content was determined by titrating a sample, which had been placed in an ampoule, with 0.1 N alkali solution. We determined the content by the difference in weight of a gram-equivalent of chlorosulfonic acid ($116.53/3$) and sulfuric acid ($98.09/2$).

Thus, in our experiments we used chlorosulfonic acid with a content of SO_3HCl from 93 to 96%, and only for the preparation of toluenesulfonyl chloride, nitrobenzenesulfonyl chloride, and naphthalenetrisulfonyl chloride did we use acid which had been distilled in vacuum at a temperature of 85 to 92° and contained not less than 99% SO_3HCl .

The preparation of the pure sodium salts of the sulfonic acids from the corresponding chlorides was carried out by heating the chloride in water or in 30 to 40% alcohol until there was complete solution. The solution was evaporated to dryness in order to remove hydrogen chloride. The sulfonic acid was dissolved, neutralized with alkali using an indicator, and the solution was concentrated until the crystallization of the salt began. The salt was dried at a temperature from 130 to 200° for about 3 hours.

The reaction was carried out in short test tubes, each closed with a stopper containing a stirring rod which could be moved inside the test tube to stir the mixture. If the reaction mixture was allowed to stand for 2 days or more, the stoppers were sealed. Heating was carried out in an Eikman apparatus [16].

SUMMARY

1. Using chlorosulfonic acid, we obtained sulfonyl chlorides from the sodium salts of eight different sulfonic acids of the aromatic series with optimal yields (for seven chlorides) which fluctuated from 85 to 97% of theory.
2. It has been shown that by means of chlorosulfonic acid, the chlorides of

different sulfonic acids which contain chlorine, or the groups CH_3 , COOH , OH , NO_2 , or SO_3H in their nucleus, may be obtained.

3. It is pointed out that the relative difficulty of formation of the sulfonyl chlorides in general depends directly on the difficulty of preparing the corresponding sulfonic acids by means of sulfonation.

LITERATURE CITED

- [1] A.A.Spriskov and N.V.Aparyeva, J.Gen.Chem. 19, 1576 (1949).
- [2] K. Heumann and P. Köchlin, Ber., 15, 1114 (1882).
- [3] V.M.Rodionov, Bull., (4) 39, 305 (1926).
- [4] Organic Syntheses, Col. Vol. I, 84 (1941).
- [5] H.Limpricht and W.Paysan, Ann., 221, 213 (1883).
- [6] German Patent 133,000 (1901); Frdl., 6, 53.
- [7] J.Stewart, Soc., 2555 (1922).
- [8] German Patent 264,786 (1912); Frdl. 11, 214.
- [9] A.Corbellini, Giorn. chim. ind. applicata, 9, 118 (1927).
- [10] Kimberly, Ann.Chem.Pharm, 114, 129 (1860).
- [11] Glutz, Schrank, J. prak. Chem., (2) 2, 223 (1871).
- [12] German patent 89997 (1896); Frdl., 4, 39.
- [13] Pazschke, J. prak. Chem., (2) 2, 418 (1871).
- [14] J.Pollak, O. Lustig, Monatsh., 55, 363 (1930).
- [15] L.Gattermann, Ber., 32, 1158 (1899).
- [16] A.A.Spriskov, J.Gen.Chem., 16, 2130 (1946).

Received January 4, 1949.

See CB translation p. 1589 ff.

THE QUESTION OF THE MOST CONVENIENT METHOD OF PREPARATION

β -ALANINE

A. N. Parshik

Biochemical Laboratory of the Institute of Oncology
of the Academy of Medical Sciences of the USSR. Leningrad

The explanation of the fate of β -alanine in animal and plant cells, its entrance into the composition of such biologically important compounds as carnosine, anserine, and pantothenic acid, the necessity of the amino acid for the synthesis of these substances, and finally, the fact that β -alanine itself is a growth factor, at least for some species of bacteria and yeasts, have been thoroughly justifiable stimuli for the development of a reliable and convenient method for the synthesis of β -alanine. And in fact, we see that both in our own country [1] and abroad - in Germany [2], in Switzerland [3], and in America [4,5] - during the past few years various methods have been proposed for the preparation of β -alanine. The essence of these methods is fundamentally the hydrogenation of cyanoacetic acid and its derivatives, [2,3], the amination of acrylonitrile, and the subsequent saponification of the β -aminopropionitrile [4], or the condensation of phthalimide with derivatives of acrylic acid [1,5]. As can be seen from the old literature [6], none of these methods contain anything that is completely new, they are only the perfection and slight modification of previously proposed methods.

Without going into details, we here consider it necessary to point out that a number of faults and difficulties to a considerable degree lessen the value of the various methods of synthesis of β -alanine and make them unsuitable under the usual laboratory conditions. Thus, the reduction of cyanoacetic ester must be carried out in an autoclave at 40 atmospheres pressure of hydrogen in the presence of an expensive catalyst, platinum oxide [2]. In the presence of nickel, this reaction goes well only with the potassium salt of cyanoacetic acid at a hydrogen pressure of 100 atmospheres and at 80° [3]. A still less convenient method is the amination of acrylonitrile [4], as here, without referring to the complete list of other faults, there is formed at the same time, along with the primary amine, the secondary amine, which is difficult to separate. The substitution of the acid saponification of β -aminopropionitrile by alkaline saponification [7] is not reflected to any degree in an improvement of this synthesis. Much better and simpler methods are the condensation of phthalimide with the esters of acrylic acid in the presence of trimethylphenylammonium hydroxide as a catalyst [1], or the condensation of phthalimide with acrylonitrile in the presence of trimethylbenzylammonium hydroxide [5]. However, the inaccessibility of the starting substance, and the conditions for carrying out this reaction, which require special skills in organic chemistry, make the use of this synthesis difficult, in particular in physiological and biochemical laboratories.

EXPERIMENTAL

The motives given above have induced us to seek the most convenient method for the preparation of β -alanine. As the result of an entire series of experiments

it has become clear that this is definitely the Hofmann transformation of succinimide, according to the method of Hoogewarf and van Dorp [8], but under the condition that the separation of the β -alanine from the reaction mixture be carried out in the form of its ethyl or methyl ester. Only this method makes it possible to free it completely from byproducts, in particular, from potassium chloride and bromide. The use of lead or silver oxides [9], and even more, of the special resin for the removal of halides [4] did not permit the attainment of this objective.

We recommend that the synthesis of β -alanine be carried out in the following manner. To a solution of 302 g of caustic potash in 2720 ml of water, 96.6 g of bromine is slowly added with stirring. The mixture is cooled to 0°, and 59.4 g of succinimide are added with gentle shaking. The mixture is then heated on the water bath at 55-60° until there is decolorization. The solution is then heated at this same temperature for 2 additional hours, and then allowed to stand overnight at room temperature. The following day, the solution is acidified with concentrated hydrochloric acid until there is a definite acid reaction to Congo red. This requires about 380 ml of acid. The solution is then evaporated in vacuum at 40-45° to dryness. The dry residue is treated first with 1 liter of warm alcohol, and then with 500 ml of cold alcohol. The insoluble precipitate of potassium chloride and bromide is filtered off on the Buchner funnel. The alcoholic filtrates are combined and concentrated in vacuum at 35° to 500 ml. This concentrated solution is cooled with ice, and dry gaseous hydrogen chloride is passed in until the solution is saturated. In order to obtain more complete esterification and to remove the residues of potassium chloride and bromide, which precipitate from the solution during the treatment of the first reaction mixture with alcohol, the liquid is evaporated a second time in vacuum at 35° until there is a dry residue. This is treated with 500 ml of absolute alcohol, and dry gaseous hydrogen chloride is again passed through the solution until it is saturated. The hydrochloride of the ethyl ester of β -alanine goes into solution during this process, and the insoluble portion, which contains potassium chloride and bromide, is removed by filtration. The filtrate is concentrated in vacuum at 35° until crystallization begins, and is then allowed to stand overnight on ice. The following day, the crystalline mass is filtered off on a Buchner funnel. About 75 g of the hydrochloride of the ethyl ester of β -alanine are obtained (this is kept in a desiccator over H_2SO_4).

The free ethyl ester of β -alanine is obtained by the decomposition of the hydrochloride in an alcohol-ether solution by means of ammonia or sodium alcoholate. In the work using ammonia, 75 g of the hydrochloride was dissolved in 80 ml of absolute alcohol, 400 ml of absolute ether was added, and the solution was cooled with ice while dry gaseous ammonia was passed in to the saturation point. The precipitated ammonium chloride was filtered off, the filtrate was freed in vacuum at 30° from alcohol and ether, and the ethyl ester of β -alanine distilled at 54-56°. Saponification of the ethyl ester of β -alanine gave free β -alanine: the ethyl ester was placed in a 2-l. round-bottomed flask, 1 l. of distilled water was added, the solution was made alkaline with ammonia, and boiled with a reflux condenser for 10 to 15 hours. Without the addition of ammonia, saponification took place very slowly. After saponification was complete, the solution was concentrated in vacuum at 35-40° until the beginning of crystallization. The yield was 30 to 35 g (65% of the theoretical amount) of pure β -alanine, with m.p. 195-196°, instead of 22 to 24 g (45% of the theoretical amount), according to reference [9].

Thus, by using our method, we not only obtained excellent purity of the final product, but also increased the yield 20%. To the list of merits of this method of preparation of β -alanine, we may also add the simplicity of all the required manipulations and the easy accessibility of the starting materials, inasmuch as the synthesis of succinimide from succinic acid and ammonia [10] presents no difficulty.

In the case of decomposition with sodium alcoholate, alcoholate containing the computed amount of metallic sodium was added with cooling to the alcoholic solution of the hydrochloride. The removal of the sodium chloride thus formed was attained by adding 200 to 300 ml of absolute ether.

Very good results were also obtained by the separation of β -alanine from the reaction mixture in the form of a carbobenzoxy compound [11], but this method was more complicated.

SUMMARY

A method is given for the preparation of β -alanine.

LITERATURE CITED

- [1] V.M.Rodianov, Jubilee Collection, Dedicated to 30th Ann. of the Great October Socialist Revolution. Press of the Acad. Sci. USSR, part 1, p. 683. (1947).
- [2] F.Weygand, Ber., 74, 256 (1941).
- [3] P. Ruggli and A.Businger, Helv. Chim. Acta, 25, 35 (1942).
- [4] R.Buc, J.H.Ford, and E.C.Wise, J.Am.Chem.Soc., 67, 92 (1945).
- [5] A.Galat, J.Am.Chem.Soc., 67, 1414 (1945).
- [6] E.Abderhalden, Biochem. Handlexikon, 4, 730 (1911); 11, 320 (1924).
- [7] J.H.Ford, J.Am.Chem.Soc., 67, 876 (1945).
- [8] S. Hoogewerf and W.B.van Dorp, Rec. trav. chim., 10, 5 (1891).
- [9] Syntheses of Organic Compounds, v. 5, 7 (1938).
- [10] Synthesis of Organic Compounds, v. 5, 76 (1938).
- [11] M.Bergmann and L.Zervas, Ber., 65, 1192 (1932).

Received January 27, 1949.

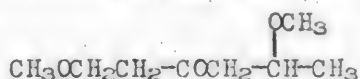
DERIVATIVES OF ACETYLENE

118. THE CONDENSATION OF VINYLACETYLENE WITH DIMETHOXYKETONES. THE SYNTHESIS AND TRANSFORMATION OF VINYLETHINYL CARBINOLS CONTAINING TWO METHOXYL GROUPS.

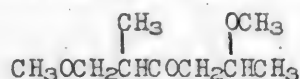
I. N. Nazarov and S. A. Vartanyan

Institute of Organic Chemistry of the Academy of Sciences of the USSR

In a previous communication [1], we have described the transformation of vinylethynyl carbinols containing a single methoxyl group. The carbinols had been obtained by the action of vinylacetylenyl magnesium bromide on the corresponding monomethoxyketone. Now we have investigated the condensation of vinylacetylene with the dimethoxyketones (I) and (II), which are easily obtained by the hydration of divinylacetylene [2] and vinylisopropenylacetylene [3] in aqueous solutions of methanol.



(I)

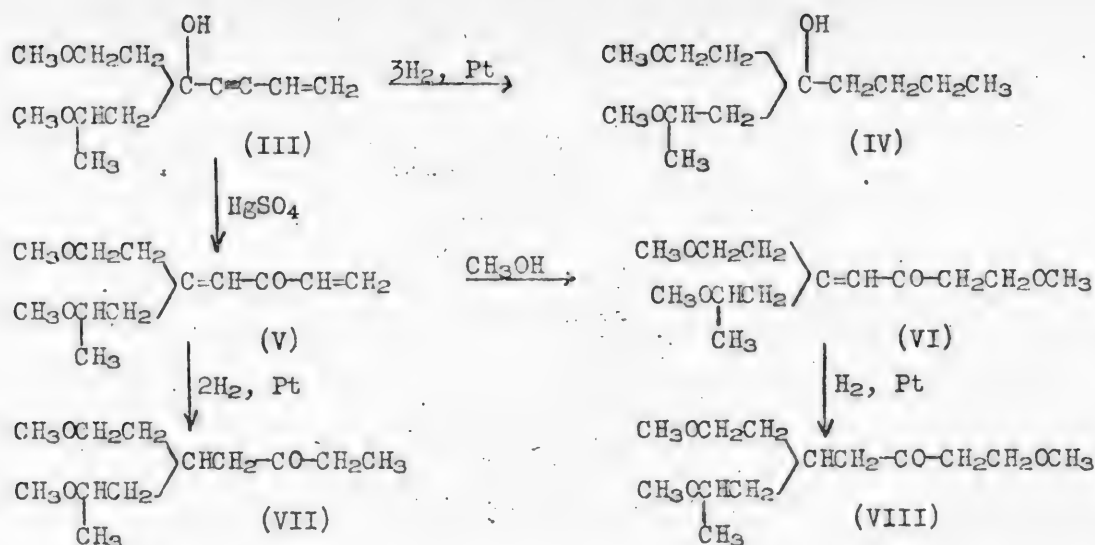


(II)

The dimethoxyketones (I) and (II), like the monomethoxyketones of similar structure, were completely incapable of condensing with vinylacetylene in the presence of powdered caustic potash, as under these conditions they were immediately condensed with the separation of methanol into solid insoluble products of high molecular weight. However, the reaction of vinylacetylenylmagnesium bromide with dimethoxyketones (I) and (II) took place normally, and led to the formation in good yield of the corresponding vinylethynyl carbinols containing two methoxyl groups. Thus, the action of vinylacetylenyl magnesium bromide on 1,5-dimethoxyhexane-3-one (I) gave in about 60% yield β -methoxyethyl- β -methoxypropylvinylethynyl carbinol (III).

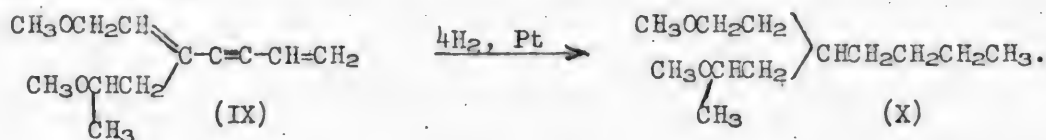
In the hydrogenation of the carbinol (III) with Pt catalyst, three molecules of hydrogen were absorbed, and β -methoxyethyl- β -methoxypropylbutyl carbinol (IV) was formed. The latter was also obtained in about 70% yield by the action of butylmagnesium chloride on the dimethoxyketone (I). Under the influence of mercuric sulfate in methanol solution, the carbinol (III), like the other vinylethynyl carbinols, is easily isomerized into 5- β -methoxyethyl-7-methoxy-1,4-octadien-3-one (V), which, under the conditions of the experiment, adds one molecule of methanol to the unsubstituted vinyl group and forms 1,7-dimethoxy-5- β -methoxyethyl-4-octen-3-one (VI). Thus, by the isomerization of the carbinol (III) in methanol solution, there can be obtained at will, depending on the duration of the experiment, either the divinylketone (V), or the trimethoxyketone (VI) which corresponds to it. However, attempts to obtain the divinylketone (V) by splitting off methanol from the trimethoxyketone (VI) under the influence of p-toluenesulfonic acid led only to tarring of the product.

In the hydrogenation of the divinylketone (V) with Pt catalyst, two molecules of hydrogen are absorbed and it is converted into 5- β -methoxyethylene-7-methoxy-



octan-3-one (VII), while in the analogous hydrogenation of the unsaturated trimethoxyketone (VI), one molecule of hydrogen is absorbed to give 1,7-dimethoxy-5-β-methoxyethyloctan-3-one (VIII). The structure of the trimethoxyketone (VI) was conclusively demonstrated by means of ozonation, which gave 1,5-dimethoxyhexan-3-one (I) and β-methoxypropionic acid.

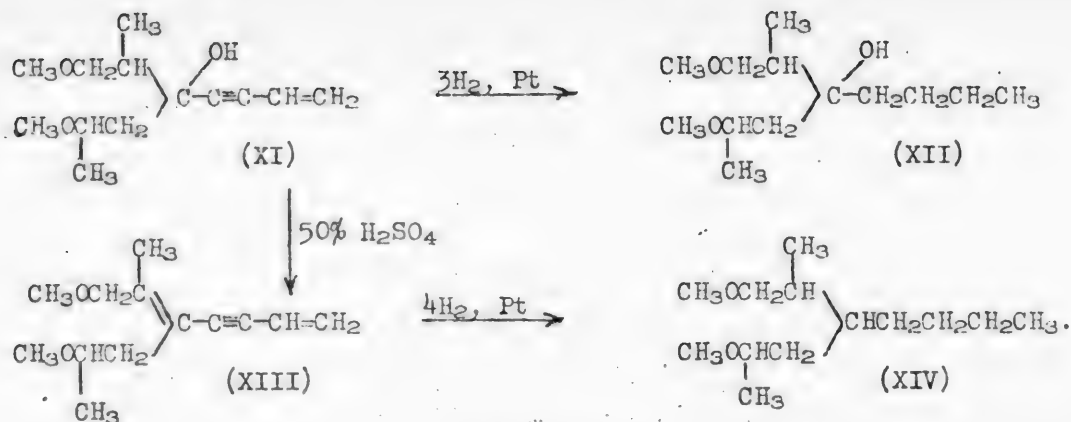
The vinyl ethynyl carbinol (III) is easily dehydrated by means of 30% sulfuric acid at a temperature of 50° and should give as a result chiefly the dienine (IX) (yield about 55%).



The dienine (IX), upon hydrogenation in a solution of alcohol in the presence of Pt catalyst, absorbed four molecules of hydrogen, and was converted into 5-β-methoxyethyl-7-methoxyoctane (X).

The hydration of the dienine (IX) in aqueous solutions of methanol (90-95%) in the presence of sulfuric acid and mercuric sulfate, took place with great difficulty, and was accompanied by considerable tarring. It gave products with extended boiling ranges, from which it was impossible to isolate individual compounds. The action of vinylacetylenylmagnesium bromide on 1,5-dimethoxy-2-methylhexan-3-one (II) also gave a 50% yield of β-methoxypropyl-β-methoxyisopropylvinylethynyl carbinol (XI), and hydrogenation of the latter with Pt catalyst gave butyl-β-methoxypropyl-β-methoxyisopropyl carbinol (XII). Dehydration of the carbinol (XI) by means of 50% sulfuric acid gave a 50% yield of the dienine (XIII), and this, upon hydrogenation with Pt catalyst absorbed the theoretically required amount of four molecules of hydrogen, and was converted into 5-β-methoxypropyl-6-methyl-6-methoxyheptane (XIV).

The vinyl ethynyl carbinols (III) and (XI), like all the other vinyl ethynyl carbinols previously investigated, upon storage without a stabilizer, gradually thickened, and were finally converted into a solid vitreous polymer. Because of the presence of two methoxyl groups, the vinyl ethynyl carbinols (III) and (XI) are distinguished by their increased sensitivity and their increased tendency to form tar. Therefore, their transformation takes place less smoothly than that of the other vinyl ethynyl carbinols.



EXPERIMENTAL

The hydration of divinylacetylene. The hydration of divinylacetylene was carried out by the method which had previously been developed in our laboratory [2]. We had carried out numerous experiments on determining the exact conditions of hydration, and in these we varied the concentration of methanol, the length of the reaction, the temperature, and the composition of the catalyst. As a result, we found that the addition of sulfuric acid to the catalyst (HgSO_4) was not obligatory. For the sake of example, we describe below several of the experiments we carried out.

a) A mixture of 500 g of 95% methanol, 100 g of divinylacetylene, 5 g of mercuric sulfate, and 0.5 g of pyrogallol was stirred at a temperature of 60-65° for 20 hours. During this time, 15 additional g of mercuric sulfate was added in small portions. The methanol was driven off in a moderate vacuum, and the product was carefully neutralized with soda, dried with sodium sulfate, and fractionated in vacuum. 104 g of products of hydration was obtained (crude 1,5-dimethoxyhexan-3-one), boiling range 94-103° at 15 mm; n_D^{20} 1.4300, tarry residue 24 g. When another similar experiment was performed, in which the heating was carried out for only 10 hours, 98 g of products of hydration was obtained.

b) 1000 ml of 95% methanol, 200 g of divinylacetylene, and 10 g of mercuric sulfate were stirred for 20 hours at a temperature of 60-65°. During this time, 15 g more of mercuric sulfate was added in small portions. 198 g of products of hydration was obtained, boiling range 91-103° at 12 mm. Upon subsequent fractionation of the products of hydration of divinylacetylene that had been obtained, 1,5-dimethoxyhexan-3-one (I) came over with b.p. 78-81° at 8 mm; n_D^{20} 1.4275.

The synthesis of β -methoxyethyl- β -methoxypropyl-vinylethynyl carbinol. In a round-bottomed flask, fitted with a mechanical stirrer, a dropping funnel, and a reflux condenser, ethylmagnesium bromide was prepared from 12 g of magnesium and 55 g of ethyl bromide in a solution of 200 ml of absolute ether. Then, through the ether solution of ethylmagnesium bromide, there was passed, while cooling was carried out with cold water, over a period of 2.5 hours, 70 g of vinylacetylene. The reaction mixture was stirred for 2 hours at room temperature and 1 hour at the boiling point of the ether until the evolution of ethane had ended completely. To the vinylacetylenylmagnesium bromide thus obtained, there was added, drop by drop, over a period of 4 hours, while cooling was carried out with water, 80 g of 1,5-dimethoxyhexan-3-one (I), dissolved in an equal volume of ether. Stirring was continued for 4 hours more at room temperature. The product was hydrolyzed with 8% hydrochloric acid (200 ml), and the ether solution was removed, neutralized with sodium bicarbonate, and dried over sodium sulfate. Fractional distillation of the product in vacuum gave 67 g of β -methoxyethyl- β -methoxypropyl-vinylethynyl carbinol (III):

B.p. 93-95° at 3.5 mm; n_D^{24} 1.4717; d_{20}^{24} 0.9623; MR_D found 61.54, computed 59.65.

5.810 mg substance: 14.520 mg CO_2 ; 5.030 mg H_2O .

4.858 mg substance: 12.139 mg CO_2 ; 4.145 mg H_2O .

Found %: C 68.20, 68.19; H 9.66, 9.55.

$C_{12}H_{20}O_3$. Computed %: C 67.90; H 9.50.

The carbinol obtained was in the form of a colorless mobile liquid with a characteristic odor. Upon standing without a stabilizer it thickened and was converted into a solid vitreous polymer with a yellow color.

The hydrogenation of β -methoxyethyl- β -methoxypropyl-vinylethynyl carbinol. 5 g of the freshly distilled carbinol (III) in a solution of 25 ml of alcohol was hydrogenated in the presence of platinum catalyst; 1.8 liter of hydrogen was absorbed instead of the 1.85 liters computed according to theory. 3.7 g of butyl- β -methoxyethyl- β -methoxypropyl carbinol (IV) was obtained in the form of a mobile transparent liquid with a pleasant odor:

B.p. 109-112° at 9 mm; n_D^{24} 1.4350; d_{20}^{24} 0.9059; MR_D found 62.81; computed 62.42.

7.886 mg substance: 19.346 mg CO_2 ; 8.480 mg H_2O .

3.413 mg substance: 8.355 mg CO_2 ; 3.655 mg H_2O .

Found %: C 66.05, 66.01; H 12.03, 11.82.

$C_{12}H_{26}O_3$. Computed %: C 66.07; H 11.92.

The action of butylmagnesium chloride on 1,5-dimethoxyhexan-3-one. Butylmagnesium chloride was prepared in a round-bottomed flask in the usual way from 5.5 g of magnesium and 18.5 g of butyl chloride in a solution of 50 ml of absolute ether. Then, while the mixture was cooled with ice water and stirred continuously, 32 g of 1,5-dimethoxyhexan-3-one in a solution of 40 ml of ether was added drop by drop. The stirring was continued for 2 hours at room temperature, and on the following day for 5 hours more at the boiling point of the ether. The product was hydrolyzed with 35% acetic acid (40 ml) extracted with ether, dried over sodium sulfate, and fractionated in vacuum. There were obtained 26 g of the butyl- β -methoxyethyl- β -methoxypropyl carbinol (IV) described above, with b.p. 109-112° at 9 mm; n_D^{20} 1.4350; d_{20}^{24} 0.9058.

The dehydration of β -methoxyethyl- β -methoxypropyl-vinylethynyl carbinol. a) A mixture of 60 g of the carbinol (III) and 60 g of 50% sulfuric acid was stirred vigorously on the water bath at 30° for 80 min. When the carbinol was mixed with the sulfuric acid, it was observed that the temperature rose from 20 to 40°. The product was extracted with ether, neutralized with a solution of soda, dried with sodium sulfate, and distilled in vacuum. There was obtained 32 g of 5-methoxypropyl-7-methoxy-1,5-heptadien-3-ine (IX) in the form of a mobile liquid:

B.p. 97-100° at 8 mm; n_D^{20} 1.4851; d_{20}^{20} 0.9250; MR_D found 60.02; computed 57.96.

3.838 mg substance: 10.419 mg CO_2 ; 3.222 mg H_2O .

Found %: C 74.08; H 9.39.

$C_{12}H_{18}O_2$. Computed %: C 74.22; H 9.27.

b) 12 g of the carbinol (III) and 12 g of phosphoric acid (sp. gr. 1.7) were stirred vigorously at a temperature of 60° for 2 hours. When the carbinol was mixed with the phosphoric acid it was observed that the temperature rose from 18 to 45°. The product was diluted with water (10 ml), extracted with ether, neutralized with a solution of soda, dried over sodium sulfate, and fractionated. There was obtained 3.5 g of the dienine (IX), with b.p. 100-103° at 9 mm; n_D^{20} 1.4950. Tarry residue 8 g.

The hydrogenation of 5- β -methoxypropyl-7-methoxy 1,5-heptadien-3-ine. 4 g of the freshly distilled dienine (IX) was hydrogenated in a solution of 25 ml of

ethanol in the presence of platinum oxide. The hydrogen absorbed was 2.2 liters; according to theory, the hydrogenation of two double bonds and one triple bond required 2.07 liters of hydrogen. There was obtained 3.5 g of 5- β -methoxyethyl-7-methoxyoctane (X), in the form of a transparent, mobile liquid.

B.p. 80-83° at 8 mm; n_D^{20} 1.4301; d_4^{20} 0.8683.

4.004 mg substance: 10.468 mg CO₂; 4.540 mg H₂O.

4.455 mg substance: 11.627 mg CO₂; 5.037 mg H₂O.

Found %: C 71.35, 71.22; H 12.69, 12.66.

C₁₂H₂₆O₂. Computed %: C 71.28; H 12.8.

Determination of methoxyl groups, according to Zeisel:

10.706 mg substance: 32.50 ml 0.01 N Na₂S₂O₃.

11.494 mg substance: 34.80 ml 0.01 N Na₂S₂O₃.

Found %: CH₃O 31.39, 31.21.

C₁₁H₂₃O(OCH₃). Computed %: CH₃O 30.68.

The isomerization of β -methoxyethyl- β -methoxypropylvinylethynyl carbinol. A mixture of 20 g of the carbinol (III), 17 g of distilled methanol, and 1 g of finely powdered mercuric sulfate was stirred for 8 hours at a temperature of 35-40°. During this time, an additional 2.5 g of mercuric sulfate was added (a total of 3.5 g). The reaction product was decanted from the catalyst, neutralized with a solution of soda, dried with sodium sulfate, and fractionated many times in vacuum. There was obtained 7.5 g of 5- β -methoxyethyl-7-methoxy-1,4-octadien-3-one (V):

B.p. 117-120° at 6 mm; n_D^{20} 1.4710; d_4^{20} 0.9682; MR_D found 61.44. computed 59.97.

12.26 mg substance: 30.45 mg CO₂; 10.45 mg H₂O.

10.60 mg substance: 26.40 mg CO₂; 9.06 mg H₂O.

Found %: C 67.79, 67.96; H 9.54, 9.56.

C₁₂H₂₀O₃. Computed %: C 67.90; H 9.50.

The hydrogenation of 5- β -methoxyethyl-7-methoxy-1,4-octadien-3-one. 4 g of the freshly distilled dienone (V) in a solution of 20 ml of ethanol was hydrogenated in the presence of platinum catalyst. The hydrogen absorbed was 0.9 liter, instead of the 0.82 liter computed according to theory. There was obtained 3 g of 5- β -methoxyethyl-7-methoxyoctan-3-one (VII) in the form of a mobile liquid:

B.p. 120-123° at 8 mm; n_D^{20} 1.4450; d_4^{20} 0.9503; MR_D found 60.50; computed 60.91.

3.775 mg substance: 9.146 mg CO₂; 3.674 mg H₂O.

3.990 mg substance: 9.672 mg CO₂; 3.868 mg H₂O.

Found %: C 66.12, 66.15; H 10.89, 11.1.

C₁₂H₂₄O₃. Computed %: C 66.6; H 11.1.

The preparation of 1,7-dimethoxy-5- β -methoxyethyl-4-octen-3-one. A mixture of 10 g of the carbinol (III), 26 g of distilled methanol, and 2 g of finely powdered mercuric sulfate was stirred for 8 hours at 40° and allowed to stand overnight. On the following day the mixture was stirred for an additional 10 hours and again allowed to stand overnight. During this period, an additional 3 g of mercuric sulfate was added (total 5 g). The reaction product was decanted from the catalyst, neutralized with a solution of soda, dried with sodium sulfate, and fractionated in vacuum. There was obtained 6 g of 1,7-dimethoxy-5- β -methoxyethyl-4-octen-3-one (VI) in the form of a yellow liquid:

B.p. 129-131° at 6 mm; n_D^{20} 1.4660; d_4^{20} 0.9932; MR_D found 67.03; computed 67.17.

12.41 mg substance: 28.88 mg CO₂; 10.81 mg H₂O.

15.28 mg substance: 35.42 mg CO₂; 13.58 mg H₂O.

Found %: C 63.50, 63.50; H 9.74, 9.94.

C₁₃H₂₄O₄. Computed %: C 63.9; H 9.83.

Determination of methoxyl groups, according to Zeisel.

14.998 mg substance: 49.16 ml 0.01 N Na₂S₂O₃.

Found %: CH₃O 33.82.

Computed %: CH₃O 37.8.

This ketone did not give crystalline derivatives with semicarbazide and 2,4-dinitrophenylhydrazine.

The hydrogenation of 1,7-dimethoxy-5-β-methoxyethyl-4-octen-3-one. 3 g of the freshly distilled trimethoxy ketone (VI) was hydrogenated in a solution of 20 ml of ethanol in the presence of Pt catalyst. The hydrogen absorbed was 300 ml (computed for one double bond, 310 ml of hydrogen). There was obtained 2.4 g of 1,7-dimethoxy-5-β-methoxyethyloctan-3-one (VIII).

B.p. 125-128° at 9 mm; n_D^{20} 1.4415; d_4^{20} 0.9680; MR_D found 67.03; computed 67.17.

4.073 mg substance: 9.430 mg CO₂; 3.815 mg H₂O.

Found %: C 63.18; H 10.48.

C₁₃H₂₆O₄. Computed %: C 63.41; H 10.57.

The ketone obtained did not give crystalline derivatives with semicarbazide and 2,4-dinitrophenylhydrazine.

The ozonation of 1,7-dimethoxy-5-β-methoxyethyl-4-octen-3-one. Ozonized oxygen was passed for 23 hours with a velocity of 4 liters per hour (concentration of ozone 5%) through a solution of 12 g of the dimethoxy ketone (V) in 60 g of dry chloroform. To the solution of the ozonide, 20 ml of water was added, and the mixture was stirred for 1 hour at a temperature of 22°; 3 g of 30% hydrogen peroxide was then added, and the stirring was continued for an additional 5 hours at 55°. The reaction mixture was neutralized with soda (5 g), and the neutral products were extracted with ether, dried with sodium sulfate, and fractionated in vacuum. There was obtained 3.0 g of 1,5-dimethoxyhexan-3-one (b.p. 75-76° at 7 mm; n_D^{20} 1.4254). The aqueous solution of salts of organic acids was evaporated to dryness on a water bath, acidified with concentrated hydrochloric acid (12 ml), and the organic acids were extracted with ether, dried with sodium sulfate, and fractionated in vacuum. There was obtained 2 g of β-methoxypropionic acid: b.p. 200-204° at 760 mm; n_D^{20} 1.4200.

0.1200 g substance: 11.33 ml 0.1 N KOH.

Found: M 106.

C₄H₈O₃. Computed: M 104.

The synthesis of β-methoxypropyl-β-methoxyisopropylvinylethynyl carbinol. In a round-bottomed flask, fitted with a mechanical stirrer, a dropping funnel, and a reflux condenser, vinylacetylenylmagnesium bromide was prepared, as described above, from 24 mg of magnesium, 110 g of ethyl bromide, and 78 g of vinylacetylene in a solution of 800 ml of absolute ether. To the vinylacetylenylmagnesium bromide which had been prepared there was added drop by drop over a period of 6 hours, while cooling was carried out with ice water, 174 g of 1,5-dimethoxy-2-methylhexan-3-one (II) [3] in a solution of an equal volume of ether. The stirring was continued for 4 hours at room temperature, and the product was carefully hydrolyzed with 8% hydrochloric acid (300 ml) while being cooled with ice water. The ether solution was separated, neutralized with soda, and dried with sodium sulfate. Fractional distillation of the product in vacuum gave 98 g of β-methoxypropyl-β-methoxyisopropyl-vinylethynyl carbinol (XI):

B.p. 106-108° at 4 mm; n_D^{20} 1.4730; d_4^{20} 0.9607; MR_D found 66.00; computed 64.68.

3.656 mg substance: 9.240 mg CO_2 ; 3.175 mg H_2O .
Found %: C 68.97; H 9.72.
 $C_{13}H_{22}O_3$. Computed %: C 69.02; H 9.79.

The carbinol obtained was in the form of a colorless mobile liquid with a characteristic odor.

The hydrogenation of β -methoxypropyl- β -methoxyisopropyl-vinylethinyl carbinol. 5 g of the freshly distilled carbinol (XI) in a solution of 20 ml of ethanol was reacted in the presence of platinum catalyst. The hydrogen absorbed was 1.78 liters instead of the 1.71 liters computed according to theory. There was obtained 3.3 g of butyl- β -methoxypropyl- β -methoxyisopropyl carbinol (XII):

B.p. 97-99° at 6 mm; n_D^{20} 1.4400; d_4^{20} 0.9134.

4.390 mg substance: 10.900 mg CO_2 ; 4.920 mg H_2O .
Found %: C 67.38; H 12.54.
 $C_{13}H_{28}O_3$. Computed %: C 67.24; H 12.07.

The dehydration of β -methoxypropyl- β -methoxyisopropyl-vinylethinyl carbinol. A mixture of 20 g of the carbinol (XI) and 20 g of 50% sulfuric acid was stirred on the water bath at 50° for 1.5 hours. The product was extracted with ether and neutralized with a solution of soda, dried with sodium sulfate, and distilled in vacuum. There was obtained 7.5 g of 1-methoxy-2-methyl-3- β -methoxypropyl-2,6-heptadien-4-ine (XIII) in the form of a mobile liquid:

B.p. 95-98° at 5 mm; n_D^{20} 1.4920; d_4^{20} 0.9117; MR_D found 65.02; computed 65.27.

3.390 mg substance: 9.305 mg CO_2 ; 3.020 mg H_2O .
3.545 mg substance: 9.735 mg CO_2 ; 3.075 mg H_2O .
Found %: C 74.86, 74.98; H 9.97, 9.70.
 $C_{13}H_{20}O_2$. Computed %: C 75.0; H 9.53.

The hydrogenation of 1-methoxy-2-methyl-3- β -methoxypropyl-2,6-heptadien-4-one. 5 g of the dienine (XIII) was hydrogenated in 20 ml of alcohol above platinum catalyst. The hydrogen absorbed was 2.1 liters instead of the 2.2 liters required according to theory. There was obtained 2.1 g of 5- β -methoxypropyl-6-methyl-7-methoxyheptane (XIV), in the form of a transparent liquid:

B.p. 75-78° at 5 mm; n_D^{20} 1.4350; d_4^{20} 0.8755; MR_D found 65.86; computed 65.62.

5.190 mg substance: 13.755 mg CO_2 ; 6.280 mg H_2O .
Found %: C 72.48; H 13.54.
 $C_{13}H_{28}O_2$. Computed %: C 72.22; H 12.94.

SUMMARY

By the action of vinylacetylenylmagnesium bromide on the dimethoxy ketones (I) and (II), the vinylethinyl carbinols (III) and (XI), containing two methoxyl groups, were obtained in 50-60% yield. The dehydration of these carbinols was effected with 50% sulfuric acid to give the corresponding dienines (IX) and (XIII) respectively. The isomerization of the vinylethinyl carbinol (III) to give the divinyl carbinol (V) was also carried out under the influence of mercuric sulfate in methanol solution. All the unsaturated compounds described above were hydrogenated in the presence of Pt catalyst to give the corresponding saturated compounds.

LITERATURE CITED

- [1] I.N.Nazarov and S.A.Vartanyan, J.Gen.Chem. 20, 1582 (1950).°
- [2] I.N.Nazarov and I.I.Zaretskaya, Bull. Acad. Sci., USSR, Div. Chem.Sci., 200 (1942).
- [3] I.N.Nazarov and I.I.Zaretskaya, Bull. Acad. Sci., USSR, Div. Chem.Sci., 211 (1941).

Received January 11, 1949.

* See CB translation p. 1643 ff.

DERIVATIVES OF ACETYLENE

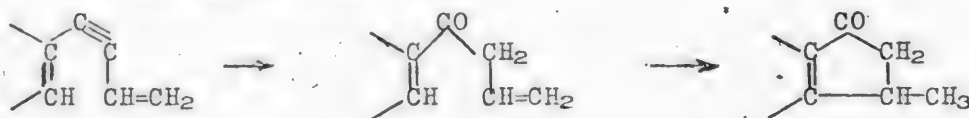
119. THE MECHANISM OF HYDRATION AND CYCLIZATION OF THE DIENINES.

XXVI. THE BEHAVIOR OF 5,6-DIMETHYL-1,5-HEPTADIEN-3-INE DURING HYDRATION AND CYCLIZATION

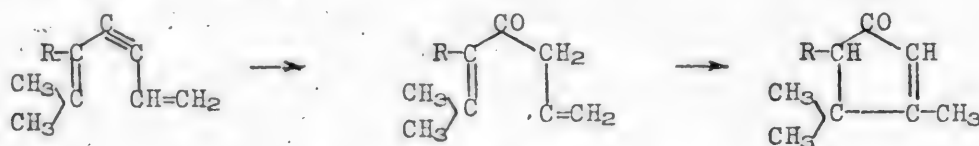
I. N. Nazarov and S. S. Bakhmutskaya

Institute of Organic Chemistry of the Academy of Sciences of the U S S R

In our laboratory, by means of numerous examples, we have systematically investigated the hydration of dienines to give the corresponding dienones (vinylallyl ketones) and the cyclization of the latter to give substituted cyclopentenones. Depending on the structure of the original dienines, hydration and cyclization can take place in two different directions. The first type of dienine gives upon hydration a vinylallyl ketone whose cyclization takes place by means of the free hydrogen of the vinyl radical [1]:



The second type of dienine, upon hydration gives a vinylallyl ketone which does not contain a free hydrogen at the end of the vinyl radical. The cyclization of this type, however, also takes place with great ease by means of the hydrogens of the allyl group [2]:



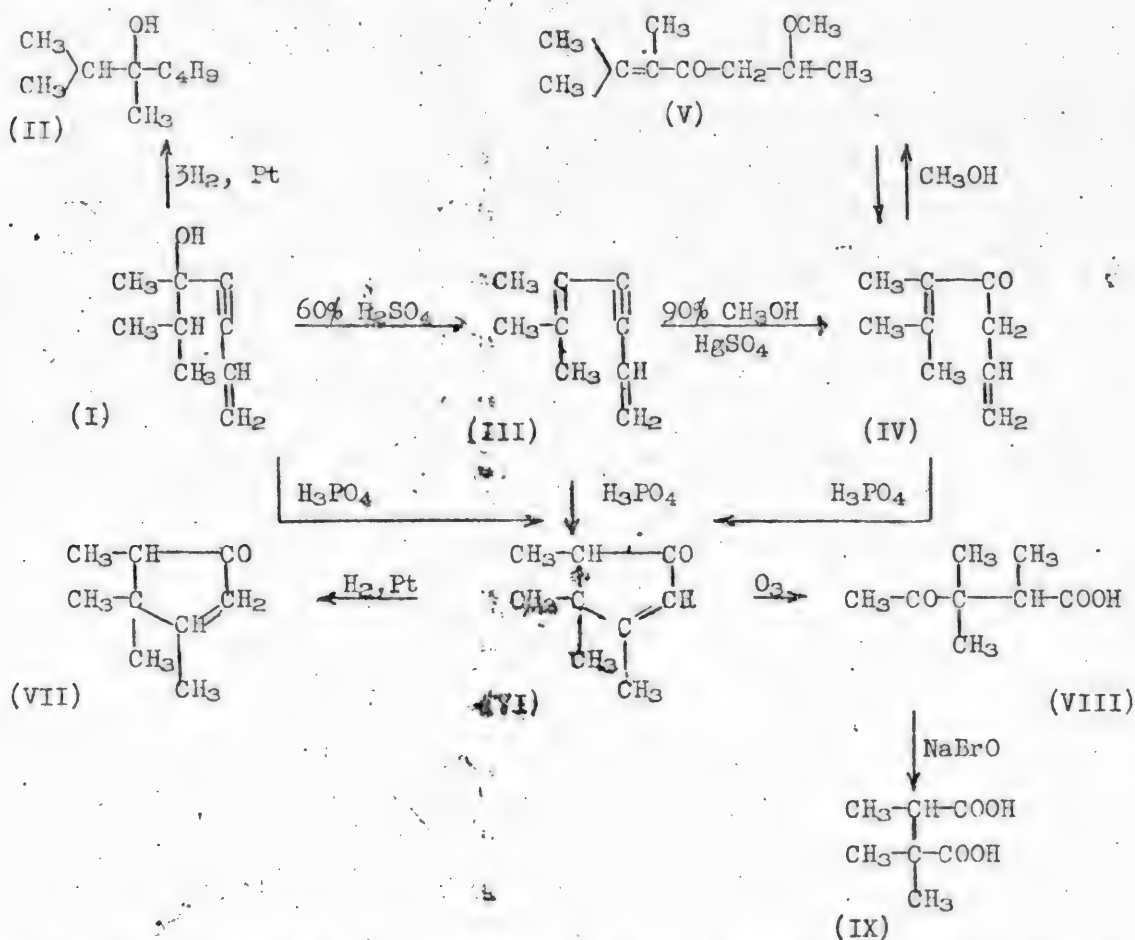
In order to explain these cyclizations, we have proposed a single ionic mechanism, whose essential features are: a) the addition of a hydrogen ion to the terminal carbon atom of the allyl radical, b) the cyclization of the unsaturated ion thus formed, and c) the stabilization of the cyclic ion with the loss of a proton (first type) or with preliminary isomerization and subsequent loss of a proton (second type) [3].

Inasmuch as the second type of cyclization had been investigated with only three of the examples described above, it was of interest to trace this new and interesting cyclization with other very simple representatives, of which we chose 5,6-dimethyl-1,5-heptadien-3-ine (III). The condensation of vinylacetylene with methylisopropylketone in the presence of powdered caustic potash gave a 72% yield of methylisopropylvinylethynyl carbinol (I). Upon hydrogenation with Pt catalyst, this absorbed 3 molecules of hydrogen and formed the known methylisopropylbutyl carbinol (II) [4]. The dienine (III), which had been designated for investigation,

was obtained in 50% yield by the dehydration of the carbinol (I) by means of 60% sulfuric acid. Among the dehydration products of the carbinol (I) we also observed a small amount of 1,2,2,3-tetramethyl- Δ^3 -cyclopenten-5-one (VI). This indicated the unusual ease of the hydration and cyclization of the dienine (III).

As was also to be expected, the cyclopentenone (VI) was easily obtained in a yield of 60% directly from the carbinol (I) by heating with phosphoric acid (sp. gr. 1.75). In this way, all three steps were accomplished in a single operation, and there was no need to isolate the intermediate products [the dienine (III) and the dienone (IV)]. The cyclopentenone (VI) was also obtained in approximately the same yield by heating the dienine (III) with phosphoric acid.

Upon hydrogenating the cyclopentenone (VI) in a solution of alcohol with Pt catalyst, it readily absorbed one molecule of hydrogen and smoothly formed 1,2,2,3-tetramethylcyclopentan-5-one (VII). In contrast to the cyclopentenones of this type which contain an open double bond in the ring (without substituents, or with a single substituent), cyclopentenones which contain two substituents at the double bond do not undergo smooth catalytic hydrogenation even in a solution of glacial acetic acid [1].



The structure of the cyclopentenone (VI) was decisively demonstrated by means of ozonation. This gave a high yield of formic acid and the α, β, β -trimethyllevulinic acid (VIII) [5] which is described in the literature. The latter was smoothly oxidized with alkaline bromine to give the also known trimethylsuccinic acid (IX) [5].

Upon heating in aqueous solutions of methanol, in the presence of mercuric sulfate, the dienine (III) was quantitatively hydrated to give 5,6-dimethyl-1,5-

heptadien-4-one (IV), which under the conditions of the experiment added one molecule of methanol and was converted into 5,6-dimethyl-2-methoxy-5-hepten-4-one (V). The pure dienone (IV) was obtained by splitting off methanol from the methoxyketone (V) by means of p-toluenesulfonic acid.

The cyclization of the dienone (IV) by means of phosphoric acid, contrary to expectations, took place in a more complicated manner than the cyclization-hydration of the dienine (III), and resulted in the formation of a mixed product, containing along with the cyclopentanone (VI) its isomer, with a double bond in a different position. Upon hydrogenation, the isomer gave the cyclopentanone (VII) described above. The structure of this second isomer was not determined.

We must note that upon hydrogenating the dienone (IV) with Pt catalyst in a solution of alcohol or glacial acetic acid, only about one molecule of hydrogen was absorbed, while during an analogous hydrogenation of the dienine (III) about three molecules of hydrogen were absorbed, and then the hydrogenation slowed down very sharply. In both cases, a difficultly separable mixture of products was obtained. These facts testify to the difficulty of hydrogenating the trimethylvinyl group in the dienine (III) and the dienone (IV) as a result of the screening influence of the substituents, as has been repeatedly noted in our laboratory previously with regard to other similar examples.

EXPERIMENTAL

Methyl isopropylketone (b.p. 91-96°; n_D^{20} 1.3870) was obtained in 58% yield by the oxidation with chromic acid mixture of methyl isopropyl carbinol, which had in turn been obtained by the action of methyl magnesium iodide on isobutyric aldehyde.

The synthesis of methyl isopropylvinylethynyl carbinol. To a round-bottomed flask containing 200 ml of dry ether and 28 g of powdered caustic potash there was added drop by drop, with cooling to -15° and continuous stirring over a period of one hour, a mixture of 50 ml of dry ether, 19 g of methylisopropyl ketone, and 31 g of vinylacetylene. The reaction mixture was then stirred for 6 hours at room temperature. The product was treated with water (50 ml), neutralized with 10% hydrochloric acid, washed with a solution of soda, dried, and fractionated in vacuum. There was obtained 25 g of methylisopropylvinylethynyl carbinol (I), in the form of a colorless polymerizing liquid, with a characteristic odor:

B.p. 64-66° at 9 mm; n_D^{20} 1.4780; d_4^{20} 0.8860; MR_D found 44.09; computed 42.82.

13.84 mg substance: 39.68 mg CO₂; 12.70 mg H₂O.

9.71 mg substance: 27.80 mg CO₂; 8.82 mg H₂O.

Found %: C 78.24, 78.13; H 10.27, 10.16.

C₉H₁₄O. Computed %: C 78.26; H 10.14.

The hydrogenation of methylisopropylvinylethynyl carbinol. 3 g of the substance was hydrogenated in 25 ml of methol in the presence of Pt catalyst, prepared according to the method of Adams. For the reduction of one double and one triple bond, it was computed that 1600 ml of hydrogen should have been absorbed; actually, 1590 ml of hydrogen was absorbed. We obtained 2.1 g of methylisopropylbutyl carbinol (II) [4], in the form of a colorless mobile liquid with a characteristic odor:

B.p. 172-174° at 760 mm; n_D^{20} 1.4365; d_4^{20} 0.8349; MR_D found 45.25; computed 45.29.

11.17 mg substance: 30.62 mg CO₂; 13.95 mg H₂O.

10.45 mg substance: 28.69 mg CO₂; 12.88 mg H₂O.

Found %: C 74.81, 74.93; H 13.97, 13.79.

C₉H₂₀O. Computed %: C 75.00; H 13.88.

The dehydration of methylisopropylvinylethynyl carbinol. 22 g of the carbinol (I) and 22 g of 60% sulfuric acid were vigorously stirred at 60-65° for a period of 40 minutes. The reaction product was extracted with ether, neutralized with soda, dried, and distilled in vacuum. There was obtained 9.7 g of 5,6-dimethyl-1,5-heptadien-3-ine (III), in the form of a mobile, yellowish, quickly polymerizing liquid:

B.p. 47-50° at 20 mm; n_D^{20} 1.5158; d_4^{20} 0.8204; MR_D found 44.16; computed 40.83.

8.99 mg substance: 29.64 mg CO₂; 8.18 mg H₂O.
10.48 mg substance: 34.52 mg CO₂; 9.43 mg H₂O.
Found %: C 89.97, 89.89; H 10.18, 10.07.
C₈H₂₀. Computed %: C 90.00; H 10.00.

During the reaction, part of the hydrocarbon was cyclized and hydrated. From several experiments on the dehydration of the carbinol (I) we obtained a cyclic ketone (b.p. 70-72° at 7 mm; n_D^{18} 1.4740) which gave a semicarbazone with m.p. 172°. This semicarbazone did not give a depression of the melting point when it was mixed with the semicarbazone of the cyclic ketone (VI), described below.

The cyclization-hydration of 5,6-dimethyl-1,5-heptadien-3-ine. 4.5 g of the dienine (III) and 4.5 ml of phosphoric acid (sp. gr. 1.75) were vigorously stirred for 2 hours at a temperature of 60-65°. After the usual treatment, 3 g of product was obtained (b.p. 76° at 9 mm; n_D^{20} 1.4695). This gave a semicarbazone which melted at 173°, and gave no depression of the melting point when it was mixed with the semicarbazone of the cyclic ketone (VI), obtained directly from the carbinol (I) and described below.

The hydration of 5,7-dimethyl-1,5-heptadien-3-ine. 8 g of the dienine (III), 35 g of 90% methanol, 0.03 ml of sulfuric acid, and 4 g of mercuric sulfate were vigorously stirred for 8 hours at a temperature of 60-65° (the mercuric sulfate was added in four 1 g portions). The product was extracted with ether, neutralized with soda, dried, and fractionally distilled. There was obtained 8.4 g of hydration products with boiling range 72-86° at 8 mm. Numerous fractional distillations of the products of hydration in vacuum gave 2.8 g of 5,6-dimethyl-2-methoxy-5-hepten-4-one (V), in the form of a yellowish mobile liquid with a characteristic odor:

B.p. 81-84° at 6 mm; n_D^{20} 1.4560; d_4^{20} 0.9216; MR_D found 50.14; computed 49.57.

9.94 mg substance; 25.75 mg CO₂; 9.54 mg H₂O.
8.65 mg substance: 22.44 mg CO₂; 8.15 mg H₂O.
Found %: C 70.70, 70.80; H 10.74, 10.55.
C₁₀H₁₈O₂. Computed %: C 70.59; H 10.59.

The rest of the product was a mixture of the methoxyketone (V) which had been obtained with 5,6-dimethyl-1,5-heptadien-4-one (IV).

The splitting off of methanol from the hydration products of 5,6-dimethyl-1,5-heptadien-3-ine. 7 g of the hydration products of the dienine (III) (boiling range 77-84° at 11 mm; n_D^{17} 1.4630-1.4535) and 0.035 g of p-toluenesulfonic acid were placed in a Claisen flask and heated for 15 minutes at 130° in a vacuum at 145 mm. During this period of time, about 1 g of methanol was driven off. After the reaction product had been cooled, it was neutralized in a separatory funnel with a solution of soda, extracted with ether, dried, and distilled in vacuum. There was obtained 5.5 g of 5,6-dimethyl-1,5-heptadien-4-one (IV), which was in the form of a light yellow, mobile, quickly polymerizing liquid with a characteristic odor:

B.p. 89-90° at 20 mm, 70-71° at 9 mm; n_D^{20} 1.4775; d_4^{20} 0.9832; MR_D found 43.69; computed 42.84.

3.833 mg substance: 11.034 mg CO₂; 3.465 mg H₂O.
3.318 mg substance: 9.525 mg CO₂; 2.930 mg H₂O.
Found %: C 78.56, 78.34; H 10.11, 9.88.
C₉H₁₄O. Computed %: C 78.26; H 10.14.

The dienone described gave a 2,4-dinitrophenylhydrazone, which precipitated with great difficulty and in very small amount after 6 hours of heating on the water bath at 60°. After recrystallization from methanol, it melted at 164°.

3.950 mg substance: 0.616 ml N₂ (24°, 733 mm).
Found %: N 17.29.
C₁₅H₁₈O₄N₄. Computed %: N 17.61.

The transformation of methylisopropylvinylethynyl carbinol into 1,2,2,3-tetramethyl- Δ^3 -cyclopenten-5-one. 13.4 g of the carbinol (I) and 14 ml of phosphoric acid (sp. gr. 1.75) were vigorously stirred for 4 hours at 60-65°. The product was diluted with 25 ml of water, neutralized with soda, extracted with ether, dried, and fractionally distilled in vacuum. There was obtained 8 g of 1,2,2,3-tetramethyl- Δ^3 -cyclopenten-5-one (VI), in the form of a yellowish mobile liquid with a characteristic pleasant camphor odor:

B.p. 74-76.5° at 8 mm; n_D^{20} 1.4752; d_4^{20} 0.9266; MR_D found 41.86; computed 41.11.

5.75 mg substance: 16.43 mg CO₂; 5.18 mg H₂O.
10.65 mg substance: 30.46 mg CO₂; 9.70 mg H₂O.
Found %: C 77.98, 78.05; H 10.08, 10.19.
C₉H₁₄O. Computed %: C 78.26; H 10.14.

The tetramethylcyclopentenone (VI) easily gave a semicarbazone, which after recrystallization from methanol melted at 173°.

4.445 mg substance: 0.853 ml N₂ (21°, 743 mm).
4.065 mg substance: 0.747 ml N₂ (20°, 767 mm).
Found %: N 21.78, 21.60.
C₁₀H₁₇ON₃. Computed %: N 21.54.

The tetramethylcyclopentenone (VI) obtained gave two 2,4-dinitrophenylhydrazones. One 2,4-dinitrophenylhydrazone, which predominated, was difficultly soluble in methanol, and melted after recrystallization from methanol at 196°:

4.275 mg substance: 0.663 ml N₂ (23°, 752 mm).
4.930 mg substance: 0.755 ml N₂ (23°, 753 mm).
Found %: N 17.70, 17.50.
C₁₅H₁₈O₄N₄. Computed %: N 17.61.

The other 2,4-dinitrophenylhydrazone, which was in small amount, was readily soluble in methanol, and after recrystallization from it melted at 160°:

4.065 mg substance: 0.615 ml N₂ (21°, 749 mm).
Found %: N 17.31.
C₁₅H₁₈O₄N₄. Computed %: N 17.61.

The hydrogenation of 1,2,2,3-tetramethyl- Δ^3 -cyclopenten-5-one. 2.5 g of the tetramethylcyclopentenone (VI) was hydrogenated in 12 ml of ethyl alcohol in the presence of Pt catalyst which had been prepared according to Adams. It was computed that in order to reduce one double bond, 450 ml of hydrogen was required. Actually, 490 ml of hydrogen was absorbed. The 1.5 g of 1,2,2,3-tetramethylcyclopentan-5-one (VII) obtained was in the form of a colorless liquid with a characteristic odor,

B.p. 182-184° at 760 mm; n_D^{20} 1.4450; d_4^{20} 0.8968; MR_D found 41.55; computed 41.57.

11.26 mg substance: 31.72 mg CO₂; 11.61 mg H₂O.

Found %: C 76.89; H 11.54.

C₉H₁₆O. Computed %: C 77.14; H 11.41.

The 1,2,2,3-tetramethylcyclopentan-5-one (VII) readily gave a semicarbazone which after recrystallization from methanol melted at 209-210°.

3.315 mg substance: 0.613 ml N₂ (24°, 755 mm)

3.290 mg substance: 0.609 ml N₂ (22°, 754 mm).

Found %: N 21.12, 21.25.

C₁₀H₁₈ON₃. Computed %: N 21.32.

The cyclopentanone (VII) obtained also readily gave a 2,4-dinitrophenylhydrazone, which melted after recrystallization from methanol at 151°.

4.080 mg substance: 0.635 ml N₂ (22°, 739 mm).

4.575 mg substance: 0.708 ml N₂ (22°, 739 mm).

Found %: N 17.51, 17.41.

C₁₅H₂₀O₄N₄. Computed %: N 17.30.

The ozonation of 1,2,2,3-tetramethyl-Δ³-cyclopenten-5-one. 5.2 g of the cyclopentenone (VI) was dissolved in 30 ml of chloroform and for a period of 9 hours, ozonized oxygen was passed through the solution at a velocity of 4 to 4.5 liters per hour (ozone concentration 6%). The ozonide was decomposed by vigorous stirring with 50 ml of water for 3 hours at room temperature and for 10 hours at 60°. Then 4.5 ml of 30% hydrogen peroxide was added, and the stirring was continued for an additional 6 hours at 60°.

The product of ozonation was neutralized with soda, and the water layer extracted with ether. This gave a total of 3 drops of neutral products, which were not investigated. The aqueous solution of salts was evaporated, acidified with concentrated hydrochloric acid, and the organic acids carefully extracted with ether to give about 0.5 g of formic acid with b.p. 59-63° at 140 mm, as determined by the calomel test.

After the formic acid had been driven off in vacuum, there remained in the distilling flask 4 g of α,β,β-trimethyllevulinic acid (VIII) in the form of a viscous, light yellow liquid, which then completely crystallized. After boiling with activated carbon and recrystallization from water, melted at 61-62° [5]:

3.160 mg substance: 6.998 mg CO₂; 2.510 mg H₂O.

5.160 mg substance: 11.573 mg CO₂; 2.962 mg H₂O.

Found %: C 60.43; 61.19; H 8.83, 8.63.

C₈H₁₄O₃. Computed %: C 60.76; H 8.85.

The α,β,β-trimethyllevulinic acid readily gave a semicarbazone which, after recrystallization from methanol, melted at 146° [3]:

4.750 mg substance: 0.792 ml N₂ (24°, 743 mm).

4.925 mg substance: 0.822 ml N₂ (23°, 744 mm).

Found %: N 18.74, 18.84.

C₉H₁₇O₃N₃. Computed %: N 19.53.

The α,β,β-trimethyllevulinic acid obtained also readily gave a 2,4-dinitrophenylhydrazone, which after recrystallization from a mixture of alcohol and benzene, melted at 154°.

4.804 mg substance: 0.680 ml N₂ (25°, 743 mm).

4.845 mg substance: 0.692 ml N₂ (25°, 743 mm).

Found %: N 15.85, 15.99.

C₁₄H₂₀O₆N₄. Computed %: N 16.56.

The oxidation of α,β,β-trimethyllevulinic acid with alkaline bromine. To a solution of 1.6 g of α,β,β-trimethyllevulinic acid in 24 ml of 10% caustic soda

there was added, drop by drop, with cooling and stirring, 4.8 g of bromine. The reaction mixture was stirred for 1.5 hours at 0° and 2.5 hours at room temperature. The formation of bromoform was observed; this precipitated out in the form of heavy drops on the bottom of the flask. After the neutral products had been extracted with ether, the aqueous solution of salts was evaporated to dryness, the residue was acidified with concentrated hydrochloric acid, the organic acids were carefully extracted with ether, and the ether extract was washed with a 1% solution of sodium thiosulfate, and dried with sodium sulfate. After the ether had been driven off, the trimethylsuccinic acid (IX) residue, which amounted to 1.5 g, completely crystallized. After boiling with activated carbon and recrystallizing from water, the trimethylsuccinic acid melted at 144° [5].

5.024 mg substance: 9.618 mg CO₂; 3.458 mg H₂O.

4.740 mg substance: 9.110 mg CO₂; 3.300 mg H₂O.

Found %: C 52.28, 52.45; H 7.70, 7.79.

C₇H₁₂O₄. Computed %: C 52.50; H 7.50.

4.94 mg substance: 6.81 ml 0.01 N NaOH.

7.52 mg substance: 10.31 ml 0.01 N NaOH.

Found: equiv. 73, 73.

C₇H₁₂O₄. Computed: equiv. 80.

The cyclization of 5,6-dimethyl-1,5-heptadien-4-one. 2.4 g of the dienone (IV) and 2.5 ml of phosphoric acid (sp. gr. 1.75) were stirred for 2 hours at 60-65°. After the usual treatment, 1 g of the cyclic ketone was obtained (b.p. 69-71° at 11 mm; n_D^{20} 1.4625-1.4725). This readily gave a semicarbazone, which melted after recrystallization from aqueous methanol at 210°.

4.270 mg substance: 0.781 ml N₂ (22°, 764 mm).

4.630 mg substance: 0.848 ml N₂ (21°, 762 mm).

Found %: N 21.28, 21.32.

C₁₀H₁₇ON₃. Computed %: N 21.54.

Upon hydrogenating 1 g of the same cyclic ketone (b.p. 73-76° at 14 mm; n_D^{20} 1.4625-60) in glacial acetic acid in the presence of Pt catalyst, one molecule of hydrogen was absorbed, and a saturated cyclic ketone was obtained. The semicarbazone of the latter, after numerous recrystallizations, melted at 210°. This semicarbazone gave a depression of the melting point with the semicarbazone, described above, of the original unsaturated cyclic ketone, and did not give a depression with the semicarbazone of the cyclopentanone (VII).

However, the action of 2,4-dinitrophenylhydrazine on this unsaturated cyclic ketone gave two products. The first dinitrophenylhydrazone was soluble with difficulty in methanol, and after recrystallization from a mixture of alcohol and benzene, melted at 201°.

4.120 mg substance: 0.638 ml N₂ (24°, 746 mm).

Found %: N 17.47.

C₁₅H₂₀O₄N₄. Computed %: N 17.50.

The second dinitrophenylhydrazone was readily soluble in methanol, and after recrystallization from it melted at 143°.

3.921 mg substance: 0.600 ml N₂ (24°, 752 mm).

Found %: N 17.40.

C₁₅H₂₀O₄N₄. Computed %: N 17.50.

SUMMARY

The condensation of vinylacetylene with methylisopropyl ketone in the presence of powdered caustic potash gave, in a yield above 70%, methylisopropylvinylethynyl carbinol (I), which upon hydrogenation with Pt catalyst absorbed three

molecules of hydrogen to give methylisopropylbutyl carbinol (II). The carbinol (I) was dehydrated by means of 60% sulfuric acid to give 5,6-dimethyl-1,5-heptadien-3-ine (III), whose hydration in aqueous solutions of methanol in the presence of mercuric sulfate gave high yields (about 90%) of 5,6-dimethyl-1,5-heptadien-4-one (IV). The latter readily added one molecule of methanol to the allyl group to give 5,6-dimethyl-2-methoxy-5-hepten-4-one (V), which, upon distillation in vacuum in the presence of p-toluenesulfonic acid, split off methanol and again formed the dienone (IV). Under the influence of phosphoric acid, the dienone (IV) was easily cyclized into 1,2,2,3-tetramethyl- Δ^3 -cyclopenten-5-one (VI), but at the same time other isomeric cyclopentenones of undetermined structure were also formed. However, the cyclopentenone (VI) was obtained smoothly, in a yield of more than 60%, directly from the carbinol (I) and the dienine (III) by treating them with phosphoric acid (sp. gr. 1.75). Upon hydrogenation of the cyclopentenone (VI) with Pt catalyst in a solution of alcohol or glacial acetic acid, one molecule of hydrogen was absorbed, and 1,2,2,3-tetramethylcyclopentan-5-one (VII) was smoothly formed. Upon similar hydrogenation of the dienine (III) and the dienone (IV) only three molecules and one molecule of hydrogen were absorbed, respectively, and then the hydrogenation slowed down sharply. This testified to the difficulty of hydrogenation in these compounds of the trimethylvinyl group $(CH_3)_2C=C-CH_3$. The structure of the cyclopentenone (VI) was conclusively demonstrated by ozonation, which gave high yields of formic acid and α,β,β -trimethyllevulinic acid (VIII), the latter being smoothly oxidized with alkaline bromine into trimethylsuccinic acid (IX).

LITERATURE CITED

- [1] I.N.Nazarov and coworkers, Bull. Acad. Sci. USSR, Div. Chem.Sci., 211 (1941); 200 (1942); 65 (1944); 529, 633 (1946); 51, 205, 277, 353 (1947); J.Gen. Chem., 18, 665, 675, 896, 903, 911, 1077, 1083 (1948); Bull. Acad. Sci. USSR, Div. Chem. Sci., 178, 184 (1949).
- [2] I.N.Nazarov and coworkers, J.Gen.Chem. 19, 1870 (1949).
- [3] I.N.Nazarov, Prog. Chem. 19, 88 (1950).
- [4] Whitmore and Southgate, J.Am.Chem.Soc., 60, 2511 (1938).
- [5] Bardhan, J.Am.Chem.Soc., 50, 2604 (1928).

Received January 11, 1949.

See CB translation p. a-331. ff.

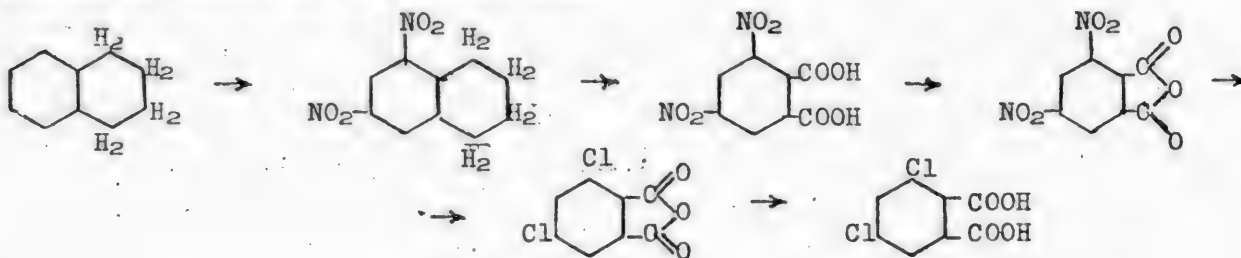
THE PREPARATION OF 3,5-DICHLOROPHTHALIC ACID

A. A. Ponomarenko and T. E. Matsievich

Department of Organic Chemistry of the I. Frank Lvov State University

Of the four possible dichlorophthalic acids, three have been obtained by the direct chlorination of phthalic acid [1] or of phthalic anhydride [2]. The fourth, 3,5-dichlorophthalic acid, has not been isolated from the chlorination products. This fact is to be explained by the predominating influence of the chlorine atom, which enters the nucleus of phthalic acid or anhydride, on the process of subsequent substitution of hydrogen by chlorine. 3,5-Dichlorophthalic acid has been obtained by the oxidation of 3,5-dichloro-o-xylene upon heating with dilute nitric acid in a sealed tube at a temperature of 190-200°. This acid has also been obtained by introducing two sulfonic acid groups into the molecule of phthalic anhydride in positions 3 and 5, and then replacing these groups by chlorine by heating with SO_2Cl_2 in a sealed tube at 180° [3].

In the present work, the acid was obtained by a method applied by one of us [4] to the preparation of monochloro phthalic anhydrides. The synthesis was carried out according to the equations:



The substitution of the nitro group begins with appreciable velocity at a temperature of 210-215°, and takes place well at a temperature from 225-235°. When 4 g of product is chlorinated, the process is complete after 7 hours. The passage of chlorine during the latter part of this period (3.5 hours) confirmed our hypothesis to the effect that in the absence of a catalyst, the further chlorination of 3,5-dichlorophthalic anhydride would not take place with appreciable velocity. Therefore, 3,5-dichlorophthalic anhydride was obtained at once fairly pure. A single sublimation was sufficient to give the anhydride with m.p. 89-90° (according to the literature, the m.p. is 89°).

EXPERIMENTAL

The nitration of tetralin and the purification of the products of nitration. 132 g of tetralin was added to a mixture of 170 g of nitric acid (sp. gr. 1.485) and 420 g of sulfuric acid (sp. gr. 1.83) which had been cooled to 0°. The temperature of the mixture did not rise above 35 to 40° [5] during the nitration. The product of nitration was washed with water until there was no further acid

reaction to litmus, then transferred to a flask, and dried in a vacuum of 30 to 40 mm for 24 hours at a temperature of 60-70°. The product, upon standing overnight, crystallized to give an unbroken yellow mass, a sample of which dissolved completely in carbon tetrachloride, thus showing the absence of any dinitronaphthalene impurity. The crude product, which consisted of isomeric dinitrotetralins, was recrystallized from glacial acetic acid and alcohol. There was obtained a eutectic with m.p. 72-73°; the amount was 73 g.

3,5-Dinitrophthalic acid. The 73 g of eutectic was placed in a retort, 800 ml of 30% nitric acid was added, and the mixture was heated on an asbestos screen until there was no further oxidation, as determined by the disappearance of the precipitation when the solution was allowed to stand overnight. The process was complete after 43 hours. The solution obtained was slowly evaporated to give a continuous white mass. The precipitate was extracted with 400 ml of hot water and the solution allowed to cool. The amorphous plastic product which precipitated was filtered off and washed with cold water. Drying gave a powder with m.p. 130-150° (with decomposition). The solution was neutralized with 400 ml of sodium acetate in the form of a solution saturated at 15-17°. The solution was heated almost to the boiling point, and to it there was added 300 ml of a solution of barium acetate saturated at room temperature. Upon cooling, a yellow precipitate of the barium salt of 3,5-dinitrophthalic acid formed. The precipitate was filtered off, decomposed by heating with concentrated sulfuric acid, and extracted with ether. After the ether had been driven off, the crude 3,5-dinitrophthalic acid was obtained with a yellow color. This was purified by three recrystallizations from water. M.p. 224-226°. Yield 20 g.

3,5-Dinitrophthalic anhydride. To 5 g of the acid which had been dried at 100-105°, there was added 30 ml of acetic anhydride, and the mixture was heated with a reflux condenser with gentle boiling for an hour. The solution was then concentrated to a small volume, and the anhydride precipitated with dried benzene. The anhydride obtained had a slight yellow color, and melted at 163°. Yield 4.3 g.

3,5-Dichlorophthalic anhydride. 4 g of 3,5-dinitrophthalic anhydride was placed in a test tube with inlet and outlet tubes, the test tube was placed in an oil bath at a temperature of 235-240°, and after the anhydride had melted, washed and dried chlorine was passed through.

The process of chlorination was discontinued when the product had m.p. 83-85°. After a single sublimation, the anhydride was obtained with m.p. 89-90°. An analysis for chlorine gave the following results:

0.1471 g substance: 13.49 ml 0.1 N AgNO₃.

Found %: Cl 35.52.

C₈H₂O₃Cl₂. Computed %: Cl 32.68.

By boiling the 3,5-dichlorophthalic anhydride with water, we obtained 3,5-dichlorophthalic acid with m.p. 164°.

SUMMARY

1. 3,5-Dinitrophthalic acid was obtained from tetralin by nitration and subsequent oxidation.
2. 3,5-Dichlorophthalic anhydride with m.p. 89-90° was obtained from 3,5-dinitrophthalic acid by chlorination of the latter's anhydride. The former was transformed into the acid in the usual manner.

LITERATURE CITED

- [1] A.L. Ruchinsky, Russian patent 41,515.
- [2] V. Villiger, Ber., 42, 3529 (1909).
- [3] H. Waldmann, E. Schwenk, Ann., 487, 287 (1931).
- [4] A.A. Ponomarenko, J. Gen. Chem. 20, 469 (1950).
- [5] G. Schroeter, Ann., 426, 17 (1922).

Received January 29, 1950.

Sr CB translation p. 501 ff.

THE SYNTHESIS OF 2-METHYLPYRROLINE

P. S. Ugryumov

The K. E. Voroshilov Scientific-Research Institute of Organic Intermediates and Dyes

MOSCOW

The preparation of sensitizers for scientific, cultural, and applied purposes is the subject of research of numerous chemists and physicists. In order to prepare dyes which can be used as sensitizers in color cinematography, 2-methylpyrroline is needed. This heterocyclic compound has special physical properties. Experimental work on the investigation and use of 2-methylpyrroline is made difficult by the fact that this substance is not very accessible. Therefore I have suggested paying a great deal of attention to new directions and methods of synthesis of 2-methylpyrroline. One of these methods is based on an accessible industrial product. I have verified the most applicable variant of the synthesis of 2-methylpyrroline in numerous experiments. In the experimental section, there is given a method of preparation which I had previously patented.

A. Lipp synthesized 2-methyl- $\Delta^{2,3}$ -tetrahydropyridine (tetrahydropicoline) by starting with bromobutylmethyl ketone [2], and this began the work which led later to the synthesis of 2-methylpyrroline. By the action of ammonia on bromobutylmethyl ketone, aminobutylmethyl ketone was obtained, and this was then closed to give a six-membered ring. This method of synthesis, and the very same reactions, were later used by other authors for the preparation of the five-membered ring of 2-methylpyrroline. The first synthesis of 2-methylpyrroline (2-methyl-4,5-dihydropyrrole) was carried out by R. Hielscher [4]. He caused an alcoholic solution of ammonia to react with γ -bromopropylmethyl ketone. The product he obtained had a boiling point of 50-51° at 110-116 mm; d_4^{22} 0.8995. The product dissolved very readily in alcohol, ether, and water. It had very powerful basic properties. G. Ciamician investigated the hydrogenation of pyrrole to give pyrroline by means of zinc dust and hydrochloric acid [5]. In this case, 3-pyrroline was formed.

The synthesis of 2-methylpyrroline can be based on the transformations of the unstable γ -aminopropylmethyl ketone. S. Gabriel [6] used sodioacetoacetic ester to convert bromoethylphthalimide into phthalimidoethylacetoacetic ester. The product mentioned was subjected to saponification, and evolved carbon dioxide, with the formation of 4-phthalimidopropylmethyl ketone. Phthalic acid was then split off by hydrolysis. This gave 4-aminopropylmethyl ketone, which, after splitting off water, gave 2-methylpyrroline, with b.p. 45° at 100 mm. The author cited reported that the product he had obtained tarred in the air, and was reduced by the action of tin and hydrochloric acid to methylpyrrolidine.

It is possible to synthesize 2-methylpyrroline from dimethylaminobutanone-(3), which has in turn been prepared by the condensation of acetone, formaldehyde, and dimethylamine hydrochloride by the method of C. Mannich [7]. This base, dimethylamino-(1)-butanon-(3), or β -acetyldimethylamine, had been obtained previously [8] by the condensation of acetone with dimethylaminohydroxymethane. The amine obtained was converted by means of nitromethane into 5-nitropentan-2-one. The oily product was subjected to vacuum distillation. The product boiled at 115°

at 12 mm. An almost colorless oil was obtained. The product gave a semicarbazone in the form of colorless needles, which melted at 141° with decomposition [9]. We find directions for the preparation of 2-methylpyrroline from 5-nitropentan-2-one in the communication of B. Reichert and H. Posemann [9].

It would have been of interest to confirm the possibility of the synthesis of 2-methylpyrroline according to the method of R.M.Hixon and coworkers [10]. For this purpose, we should have had to carry out a series of consecutive syntheses: trimethylene glycol \rightarrow trimethylene chloranhydrin \rightarrow trimethylene chlorobromide \rightarrow \rightarrow chlorobutyronitrile (the nitrile of chlorobutyric acid) \rightarrow the ketoimide \rightarrow \rightarrow 2-methylpyrroline. By this method, R.M.Hixon and his coworkers obtained 2-ethylpyrroline and 2-phenylpyrroline. Still earlier than this group, P. Lipp and H. Seeles [11] described the formation of 2-phenylpyrroline by the reaction of γ -chlorobutyronitrile with the Grignard reagent. The ketoimine derivative first obtained was converted into pyrroline hydrochloride.

Thus, supplied with a number of experiments of our predecessors, we returned to the first synthesis of 2-methylpyrroline, which is distinguished by its great superiority above the remaining methods. It is true that Wohlgemuth [12] under analogous conditions, could not obtain alkylpyrroline. None the less, D.B.Clock confirmed the synthesis of R. Hielscher by the example of 2-phenylpyrroline, but found this synthesis in many respects inapplicable for preparative purposes [13]. The reaction took place with great difficulty, and the yield of product amounted in all to only 10%. A Lipp and E.Widmann, and then S.C.Craig, E. Bulbrook, and R.M.Hixon [10] found that in aqueous solutions, a 2-alkylpyrroline was converted into 4-aminopropylalkyl ketone.

In view of this divergence in the opinions of different authors, I decided to devote myself to this synthesis. I took as my starting material 5-bromopentan-2-one. The synthesis of 5-bromopentan-2-one was carried out with acetopropyl alcohol, obtained either from acetoacetic ester and ethylene oxide or from the wood pulp by-product sylvan (methyl furan) by the method suggested by the Russian chemist A.A.Pryanishnikov. Acetopropyl alcohol is obtained in great amount by modern technical processes directly from such a wood product as furfural. It was these very technical attainments which I relied upon for access to materials I needed, which reminded me of the fact that the time had arrived to reevaluate the directions and methods of synthesis of 2-methylpyrroline.

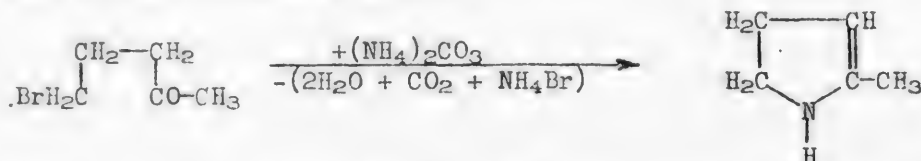
Now the task consisted of finding the proper conditions for the reaction and improving the results in comparison with those of R. Hielscher. In the transition from 2-methylpyrroline to 2-ethylpyrroline or 2-phenylpyrroline, the stability of the compound increases [10]. Here we have an expression of the influence of the radicals on the valence properties of the nitrogen atom in the pyrroline nucleus. The molecules of 2-methylpyrroline in aqueous solutions react with the molecules of water, and thus form 4-aminopropylmethyl ketone [3], while 2-ethylpyrroline reacts with water only upon heating on the water bath for a period of 1 hour, and only under these conditions does the breaking of the ring occur [10]. The 3-pyrrolines obtained by reduction of the pyrroles differ considerably from the 2-pyrrolines, which in contrast with the others, form tars in the air and are reduced by tin and hydrochloric acid to pyrrolidines. Treatment with benzoyl chloride in an aqueous solution of caustic soda breaks the ring of 4,5-dihydropyrroles to give γ -benzoylamino ketones. The salts of 1-phenyl-2-pyrroline are distinguished by their great stability. These theoretical considerations and observations of the majority of authors also served as a reason to induce me to investigate anew the conditions of formation of 2-methylpyrroline from 5-bromopentan-2-one.

EXPERIMENTAL

5-Bromopentan-2-one. The technical product from the "Akrikhin" factory was

in the form a 50% solution of 5-bromopentan-2-one in benzene. The dark liquid was evaporated to half its volume, and the product remaining in the flask was distilled at 73° and 60 mm pressure. It was in the form of a colorless liquid, which, however, darkened upon standing.

The reaction with ammonium carbonate. In accordance with stoichiometric proportions, the reaction between 5-bromopentan-2-one and ammonium carbonate should take place as in the following equation.



A mixture which consisted of 165 g of the bromoketone (1 mole) and 192 g of ammonium carbonate (2 moles) was heated in a flask which had been fitted with a wide air condenser on an oil bath, with stirring for 5 hours up to 200°. During this, a large quantity of white vapors was given off. From time to time it was necessary to brush back into the reaction flask the ammonium carbonate which had sublimed on the walls of the condenser. The unreacted ammonium carbonate was decomposed. The base was obtained by extraction and distillation. However, all attempts to obtain a considerable amount of 2-methylpyrroline were unsuccessful.

The use of such ratios of the components as 1 mole of bromoketone to 6 moles of ammonium carbonate did not influence the results of the experiment. The use of different temperatures and variation in the duration of the reaction gave no definite indications concerning optimal conditions.

It was very obvious that a solution of the difficulty must be sought in the selection of a solvent and in the use of other ammonium salts. I did not succeed in testing the action of ammonium acetate on the bromoketone in glacial acetic acid.

The reaction with liquid ammonia. In an autoclave there were placed 82 g of bromoketone, 80 g of liquid ammonia, and methanol as catalyst. The addition of ammonia was carried out from a standard ammonia cylinder through an intermediate calibrated sleeve, cooled with a mixture of ice, calcium chloride, and acetone to the temperature of liquefaction of ammonia. The autoclave was subjected to heating to 80° over a period of 6 hours. The autoclave was then cooled, the pressure was released, and the product was washed out with a solvent. After the removal of the solvent, the base was fractionated. The yield of 2-methylpyrroline amounted to 16 g (40% of theory).

The reaction in alcoholic ammonia. A solution of 80 g of 5-bromopentan-2-one in 700 ml of dry methanol saturated with ammonia was placed in an autoclave and heated up to 130° for 6 hours. The autoclave was then cooled, and the top of the autoclave was then opened under a draft. The reaction mass was removed and the autoclave rinsed out with alcohol. The residue of ammonium bromide was filtered off and discarded. The filtrate was evaporated under vacuum to a viscous syrup. To the residue there was added 50 ml of a solution of caustic alkali, and the base was driven off with steam. During the distillation of the 2-methylpyrroline with steam, frothing was observed. The main portion of the product went over with the steam during the first minutes of the distillation. The end of the distillation was indicated by the absence of the odor of 2-methylpyrroline in the distillate and the presence of only a very weak reaction on phenolphthalein. The distillate was acidified with hydrochloric acid until there was a weakly acid reaction to Congo red, and concentrated under vacuum to approximately 150 ml. Then, with good cooling, 40 ml of a 60% solution of caustic potash was added, and the

base was separated in a separatory funnel. The product was carefully dried over fused caustic potash and distilled at atmospheric pressure. B.p. 105-110°. The yield of 2-methylpyrroline amounted to 25 g (62% of theory).

This method for the preparation of 2-methylpyrroline differed from all the others previously known in that the reaction was here carried out in an autoclave and at higher temperature, thus hastening the amination and the formation of the 5-membered ring.

The 2-methylpyrroline obtained was in the form of a volatile, watery, easily mobile transparent liquid, which even upon very long standing underwent little yellowing, and then turned brown, indicating partial decomposition. The base had a strong pyridine odor. It was slightly soluble in water, and dissolved well in organic solvents. During analysis it was observed that different samples of 2-methylpyrroline, because of its considerable volatility and low combustibility, did not at first give the same results. Only with careful work was it possible to obtain complete combustion of this substance, and to obtain analytical data that were in agreement.

3.14 mg substance: 8.29 mg CO₂; 3.01 mg H₂O.

5.11 mg substance: 13.59 mg CO₂; 4.87 mg H₂O.

4.35 mg substance: 0.623 ml N₂ (18°, 751 mm).

2.91 mg substance: 0.422 ml N₂ (20°, 754 mm).

Found %: C 72.00, 72.53; H 10.73, 10.66;

N 16.61, 16.76.

C₅H₉N. Computed %: C 72.20; H 10.94; N 16.86.

SUMMARY

2-Methylpyrroline was synthesized from 5-bromopentan-2-one by a previously given method.

LITERATURE CITED

- [1] P.S. Ugrymov, Author's certificate No. 71,391, granted December 22, 1947.
- [2] A. Lipp, Ber., 19, 2843 (1886); 25, 2190, 2197 (1892); 38, 2471 (1905); Ann., 289, 173 (1896).
- [3] A. Lipp and E. Widmann, Ann., 409, 79 (1915).
- [4] R. Hielscher, Ber., 31, 277 (1898).
- [5] G. Ciamician, Ber., 34, 3954 (1901).
- [6] S. Gabriel, Ber., 42, 1241, 1247 (1909).
- [7] C. Mannich, Archiv. pharm., 255, 266 (1917).
- [8] German Patent 254,714, November 7, 1911, Fridlaender, V. II.
- [9] Benno Reichert and Heinz Posemann, Archiv. pharm., 275, 67-83 (1937).
- [10] S.C. Craig, E. Bulbrook, D.F. Starr, and R.M. Hixon, J. Am. Chem. Soc., 53, 1831 (1931); 54, 3971 (1932).
- [11] P. Lipp and H. Seeles, Ber., 62, 2456 (1929).
- [12] Wohlgemuth, Ann. chim., (9) 2, 441 (1914).
- [13] J.B. Cloce, J. Am. Chem. Soc., 51, 1184 (1929).

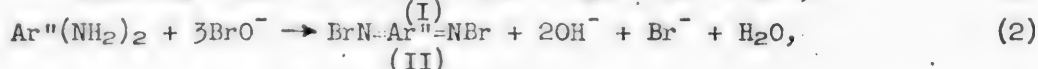
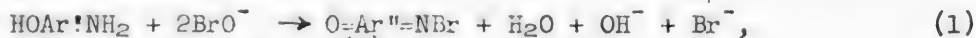
Received August 7, 1948.

QUINONEBROMOIMIDES AND QUINONEDIBROMODIIMIDES

S. I. Burmistrov and N. A. Zuykova

Vladivostok Chemical-Technological Institute

One of the present authors [1] has previously demonstrated the formation of quinonebromoides and quinonedibromodiimides not yet described in the literature. The first representative of the new class of compounds, 1,4-benzoquinonedibromodiimide, was recently described by one of us [2]. It appeared that the most convenient method of preparation of quinonebromoides (or of the quinonedibromodiimides, respectively) was by the action of an alkaline solution of hypobromite on p-aminophenol (or, on the p-diamine, respectively). The formation of quinonebromoides and quinonedibromodiimides, as has been explained, takes place according to the stoichiometric equations (1) and (2):



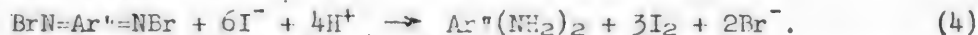
where Ar[·] is a bivalent aromatic radical, an arylene.

The quinonebromoides (I) and quinonedibromodiimides (II) are lightly colored crystalline substances, almost insoluble in water, and readily soluble in ether and benzene. Upon heating, they decompose violently, without melting. They react with phenol and naphthol in the same way as the quinonechloroides [3] and form indophenols and N-bromindamines, which are colored violet and blue in the ionic form. The quinonebromoides and quinonedibromodiimides indicated in Table 1 have been isolated in pure form and analyzed.

It was found previously that quinonebromoides and quinonedibromodiimides which correspond to a high oxidizing potential of Ar[·]O₂, the quinone, may be quantitatively determined iodometrically. The reaction of a quinonebromoidide with an iodide takes place quantitatively according to the following stoichiometric equation:



With quinonedibromodiimide, iodide reacts in some cases precisely in accord with the stoichiometric equation:



But if the quinonebromoidide (or quinonedibromodiimide) corresponds to a quinone, Ar[·]O₂, with a low oxidizing potential (below 0.60 V), the reaction with iodide does not take place quantitatively. In Table 2 are given the results of the iodometric determination of the oxidizing equivalent for the quinonebromoides and quinonedibromodiimides investigated, and the literature data on the oxidation potentials of the quinones, Ar[·]O₂, and the quinoneimides. The table shows that the oxidizing equivalent cannot be accurately determined.

These results correspond to what may be expected theoretically, as the quinoneimines obtained as intermediates in reaction (5) and the quinonedimines in

TABLE 1

The properties of quinonebromoimides and quinonedibromodiimides

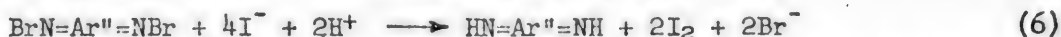
Name	Appearance	Decomposition temperature	Color in NH ₃	
			With phenol	With 1-naphthol
1,4-Benzoquinone-bromoimide.....	Golden yellow needles	67°	Blue	Violet
1,4-Naphthoquinone-bromoimide.....	Yellowish crystals	80	-	Blue
1,4-Benzoquinone-dibromodiimide.....	Light yellow needles	92	Blue	Violet
2,5-Toluoquinone-dibromodiimide.....	Light yellow needles	77	Blue	Violet
2-Chloro-1,4-benzoquinonedibromodiimide.....	Light yellow needles	74.5	Blue	Violet
2-Methoxy-1,4-benzoquinonedibromodiimide.....	Light greenish-yellow crystals	74.5	Blue	Blue
1,4-Naphthoquinonedibromodiimide.....	Light yellow needles	102	-	Blue

TABLE 2

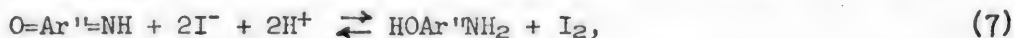
The iodometric determination of quinonebromoimides and quinonedibromodiimides

Name	Oxidation equivalent	E ₀ for Ar'O ₂	E ₀ for the quinoneimide	E ₀ for the quinonediiimide
1,4-Benzoquinonebromoimide.....	$\frac{1}{2}$ C ₆ H ₄ ONBr	0.711	0.733	0.783
1,4-Naphthoquinonebromoimide.....	-	0.483	0.542	0.644
1,4-Benzoquinonedibromodiimide.....	$\frac{1}{8}$ C ₆ H ₄ N ₂ Br ₂	0.711	0.733	0.783
2-Chloro-1,4-benzoquinonedibromodiimide.....	$\frac{1}{8}$ C ₆ H ₃ N ₂ ClBr ₂	0.736	-	-
2-Methoxy-1,4-benzoquinonedibromodiimide.....	$\frac{1}{8}$ C ₇ H ₈ ON ₂ Br ₂	0.594	-	-
1,4-Naphthoquinonedibromodiimide.....	-	0.483	0.542	0.644

reaction (6)



react quantitatively with iodide only when their oxidizing potentials are greater than the oxidizing potential of the iodine (+0.62 V). If the oxidizing potential of the quinonimine (or quinonediiimine) is less than the oxidizing potential of the iodine, then the reactions



are to a considerable extent reversed, and the quantitative separation of iodine

does not take place. It is also of interest to note that the quinonedibromodiimides which correspond to quinones with a low oxidizing potential do not react with phenol, but only with 1-naphthol. A quinonebromoimide reaction is also observed for those p-diamines which correspond to a high oxidizing potential (greater than 0.54 V) of the quinones [4].

In the preceding work it was shown that the quinonebromoimide reactions give not only aminophenols, but also their alkyl ethers. Therefore, it appeared of interest to find experimental proofs of the fact that quinonebromoimides can be obtained from the alkyl ethers of aminophenol by the action of hypobromite. As was later described, the action of hypobromite on 4-aminoanisole gave a substance which from its properties and the results of its analysis was identified as 1,4-benzoquinonebromoimide. This showed the cleavage of the methyl group from 4-aminoanisole by the action of the hypobromite.

EXPERIMENTAL

We obtained the quinonebromoimides and quinonedibromodiimides by pouring a solution of p-aminophenol or p-diamine into a cooled solution of hypobromite. The precipitate of quinonebromoimide was filtered off and crystallized from a mixture of benzene with gasoline, or with petroleum ether. The temperature of solution in benzene should not be above 60°. The synthesis of 1,4-benzoquinonedibromodiimide has been described previously [2]. The results of the synthesis of other quinonebromoimides and quinonedibromodiimides are given further on.

1,4-Benzoquinonebromoimide. $\text{BrN}=\text{C}_6\text{H}_2=\text{O}$. This was obtained by the action of hypobromite on p-aminophenol hydrochloride. The crystals of benzoquinonebromoimide were filtered off on a suction funnel, washed with water, and crystallized from benzene. The crystals were golden-yellow leaves, very soluble in benzene, soluble with more difficulty in gasoline, and with great difficulty in alcohol, almost insoluble in water. Heating resulted in decomposition, with deflagration at 67°. It formed brown stains on the skin. It gave a blue color with phenol.

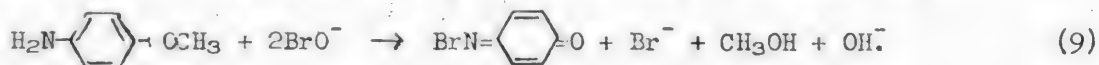
0.2054 g substance: 39.31 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

0.1240 g substance: 23.62 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

Found: equivalent 46.74, 47.29.

$\frac{1}{4} \text{C}_6\text{H}_4\text{ONBr}$. Computed: equivalent 46.48.

The cleavage of the ethers of aminophenol with hypobromite. Under the action of hypobromite on 4-aminoanisole there took place, as has been shown, the formation of 1,4-benzoquinonebromoimide. The presumed course of the reaction is:



It is possible that not methyl alcohol, but products of its oxidation are formed.

A solution of 6.1 g (0.05 mole) of 4-aminoanisole in 100 ml of water and 10 ml of hydrochloric acid which had been diluted with an equal volume of water was poured into an ice-cooled solution of hypobromite which had been obtained from 40 g of bromine (0.5 mole) and 20.9 g of NaOH in 300 ml of water. The brownish-yellow precipitate was filtered off, washed on the funnel, and the water removed by suction, and crystallized from benzene. Golden-yellow leaves were obtained.

0.0994 g substance: 18.98 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

0.1266 g substance: 24.11 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

Found: equivalent 47.38, 47.52.

$\frac{1}{4} \text{C}_6\text{H}_4\text{ONBr}$. Computed: equivalent 46.48.

From all of its reactions, and from the results of its analysis, the substance was identical with the benzoquinonebromodiimide obtained from 1,4-aminophenol.

1,4-Naphthoquinonebromodiimide, $O=\text{C}_6\text{H}_4\text{C}(\text{NBr})_2$. This was obtained from 1,4-amino-



naphthol by the action of hypobromite. The precipitate of quinonebromodiimide was crystallized from benzene (solution at 40°). The fine light yellow crystals were very soluble in benzene, soluble with more difficulty in gasoline, and almost insoluble in alcohol and in water. Heating in a capillary up to 80° resulted in decomposition. It gave a blue color with 1-naphthol, but not with phenol.

0.3226 g substance: 13.45 ml 0.1 N HCl (Kjeldahl, after reduction).
Found %: N 5.88.

$\text{C}_{10}\text{H}_6\text{ONBr}$. Computed %: N 5.97.

2-Chloro-1,4-benzoquinonedibromodiimide, $\text{BrN}=\text{C}_6\text{H}_3(\text{Cl})(\text{NBr})$. This was obtained



from the 1,4-phenylenediamine by the action of hypobromite, in the same way as 1,4-benzoquinonedibromodiimide. It was in the form of light yellow needles, readily soluble in benzene, almost insoluble in water, and very difficultly soluble in alcohol. It decomposed upon heating to 77° .

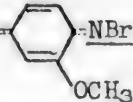
0.966 g substance: 19.36 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

0.931 g substance: 19.11 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

Found: equiv. 49.88, 49.49.

$\frac{1}{8} \text{C}_6\text{H}_3\text{N}_2\text{ClBr}_2$. Computed: equiv. 49.73.

2-Methoxy-1,4-benzoquinonedibromodiimide, $\text{BrN}=\text{C}_6\text{H}_3(\text{OCH}_3)(\text{NBr})$. This was obtained



from 2,5-diaminoanisole (whose preparation has been previously described) by the action of hypobromite. It was a very slightly greenish-yellow powder from benzene (solution at 40°). It was readily soluble in benzene, soluble with difficulty in alcohol, and almost insoluble in water. In the air and light it quickly darkened. Upon heating to 74.5° it decomposed with the evolution of soot. With phenol it gave a blue color.

0.0889 g substance: 18.66 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

0.0987 g substance: 19.10 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

0.1015 g substance: 20.97 ml 0.1 N $\text{Na}_2\text{S}_2\text{O}_3$.

Found: equiv. 50.45, 50.51, 50.45.

$\frac{1}{8} \text{C}_7\text{H}_5\text{ON}_2\text{Br}_2$. Computed: equiv. 48.98.

The analysis of 2-methoxy-1,4-benzoquinonedibromodiimide was carried out also by the determination of nitrogen by the Kjeldahl method. For this purpose, a sample of the quinonedibromodiimide was dissolved in alcohol, bisulfite was added, and after heating until reduction took place, sulfuric acid was added plus a small drop of mercury. The heating with sulfuric acid led, as is usually the case, to decolorization of the solution.

0.2948 g substance: 18.85 ml 0.1 N HCl.

Found %: N 8.98.

$\text{C}_7\text{H}_5\text{ON}_2\text{Br}_2$. Computed %: N 9.52.

2,5-Diaminoanisole, $\text{H}_2\text{N}-\text{C}_6\text{H}_3(\text{OCH}_3)-\text{NH}_2$. The 2,5-diaminoanisole, which was needed

for the synthesis of 2-methoxy-1,4-benzoquinonedibromodiimide, was obtained by us by the reduction of 5-nitro-2-aminoanisole with sodium sulfide. So far as we know this diamine has not yet been described in the literature. It is in the form of rose-colored leaves (from benzene), very soluble in water. M.p. 103.5°.

0.1436 g substance: 20.54 ml 0.1 N HCl (Kjeldahl).

Found %: N 20.30.

$\text{C}_7\text{H}_{10}\text{ON}_2$. Computed %: N 20.28.

As a result of the low degree of stability of the free base, it was convenient to obtain the sulfate of the diamine by the following method: 167 g (0.1 mole) of 5-nitro-2-aminoanisole was dissolved in 75 ml of alcohol, 36 g of zinc dust (0.5 g-atom) was added, and a solution of 5 g of NaCl in 15 ml of water. The mixture was heated on the water bath. The heating was continued until the disappearance of the yellow color of the solution. A few minutes were needed for this. The zinc oxide and the excess of zinc dust were filtered off, and to the solution there was added 0.1 mole of sulfuric acid which had been diluted with twice its volume of water. The precipitate of 2,5-diaminoanisole sulfate was cooled and filtered. For analysis, the sulfate was crystallized from water. It was in the form of a rose-colored powder, slightly soluble in cold water.

0.3092 g substance: 23.12 ml 0.1 N HCl (Kjeldahl, after reduction).
Found %: N 12.09.

$\text{C}_7\text{H}_{10}\text{ON}_2 \cdot \text{H}_2\text{SO}_4$. Computed %: N 11.86.

1,4-Naphthoquinonedibromodiimide, $\text{BrN}-\text{C}_{10}\text{H}_6-\text{NBr}$. This was obtained from 1,4-

naphthalenediamine hydrochloride by the action of hypobromite. The crystals had a sandy color (from benzene, solution at 40°). It was very soluble in benzene, insoluble in water and in alcohol. It slowly darkened in the light. Upon heating, it decomposed at 102°. On the skin it formed brown stains. It gave no color with phenol in ammonia, a blue color being obtained only with 1-naphthol.

0.3090 g substance: 19.42 ml 0.1 N HCl (Kjeldahl, after reduction).
Found %: N 8.30.

$\text{C}_{10}\text{H}_6\text{N}_2\text{Br}_2$. Computed %: N 8.73.

2,5-Toluoquinonedibromodiimide, $\text{BrN}-\text{C}_6\text{H}_3(\text{CH}_3)-\text{NBr}$. This was obtained from 2,5-

diaminotoluene by the action of hypobromite, in the form of light yellow needles which darkened in the light. It was very soluble in benzene, and therefore an attempt to crystallize it from the solution did not result in giving enough of it for analysis. Decomposition temperature 77°.

SUMMARY.

1. Representatives of a new class of compounds, quinonebromoimides and quinonedibromodiimides, hitherto undescribed in the literature, have been obtained for the first time.

2. The properties and reactions of two quinone bromoimides and four quinone-dibromodiimides have been described.

3. It has been shown that quinonebromimides which correspond to quinones with high oxidizing potentials can be determined iodometrically.

4. It has been shown that alkyl ethers of p-aminophenols also form quinonebromimides with hypobromite. This has served as experimental proof of the cleavage of the alkyl group by the action of hypobromite on 4-aminoanisole.

LITERATURE CITED

[1] S.I.Burmistrov, Communication on the Scientific-Technical reports of the Members of the D.I.Mendeleev All-Union Chem.Soc., No. 2, 5 (1946).

[2] S.I.Burmistrov, J.Anal.Chem., 4, 60 (1949).

[3] R.Mohlau, Ber., 16, 2845 (1883).

[4] S.I.Burmistrov, J.Anal. Chem. 1, 965 (1946).

Received January 22, 1949.

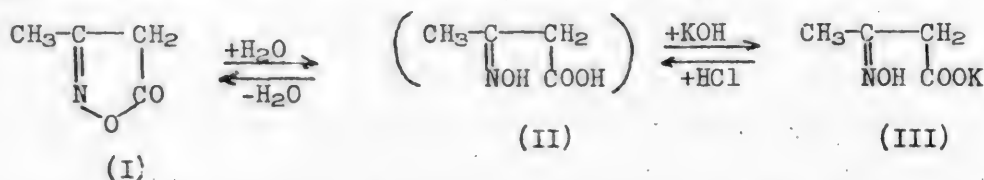
THE OXIME OF ACETOACETIC ACID (β -HYDROXYIMINO BUTYRIC ACID)

N. V. Khromov

Dyestuff Laboratory of the Leningrad Technological Institute

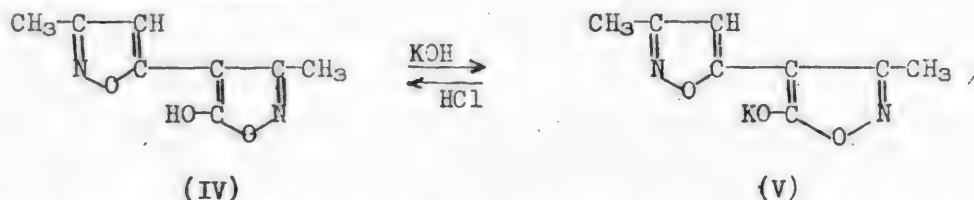
The oxime of acetoacetic acid has not been obtained up to the present time. In the opinion of Hantzsch [1,2], he synthesized its inner anhydride from methyl isoxazolone. Hantzsch assumed that free β -hydroxyiminobutyric acid was present in aqueous solutions of methyl isoxazolone and this, in his opinion, was the cause of the strong acid reaction of aqueous solutions of methylisoxazolone. To the salts which methyl isoxazolone forms with alkalis Hantzsch ascribed the structure of salts of β -hydroxyiminobutyric acid [3]; but up to the present time no one has succeeded in isolating this acid in the free form. When solutions of salts obtained from methyl isoxazolone and alkali are acidified, there is an immediate formation of methyl isoxazolone.

The reaction of methyl isoxazolone with alkali, as well as the reaction of its salts with acids, can, according to Hantzsch, be expressed by the following equation:



This picture of the structure of methyl isoxazolone (I) and its salts (III) has been reflected both in reference books [2] as well as in textbooks of organic chemistry [4,5]. However, this picture is erroneous. At present we must consider that it has been decisively demonstrated [6,7] that methyl isoxazolone does not have the formula of an inner anhydride of β -hydroxyiminobutyric acid (I), but is the product of the anhydro condensation of two such molecules and is in the form of 3,3'-dimethyl-5-hydroxy-4,5'-diisoxazolyl (IV).

It has been shown also that during the formation of the salt (V), it unites with only one equivalent of alkali:

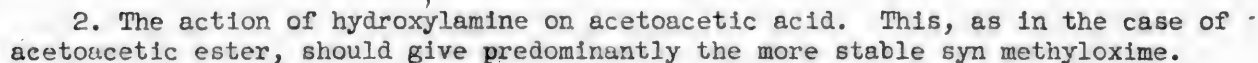


We must therefore reject the old ideas of Hantzsch not only concerning the structure of methyl isoxazolone, but also concerning the ease and the reversibility of the transformation of the latter into β -hydroxyiminobutyric acid. Thus, the

For the sake of brevity we shall refer to it as the anhydride of methyl isoxazolone.

At the same time, the ethyl ester of this acid (the oxime of acetoacetic ester) exists in the form of a fairly stable compound, and can be converted into the anhydride of methylisoxazolone only with difficulty. The stability, and the unexpected difficulty of cyclization of the oxime of acetoacetic ester in comparison with the oxime of benzoylacetic ester is to be explained, according to our assumption [7], by the different spatial orientation of the hydroxyimino groups in these two esters. These considerations concerning the spatial cause of the stability of the oxime of acetoacetic ester led us to believe that the syn methyloxime of acetoacetic acid might also be a comparatively stable compound, and like the oxime of acetoacetic ester, should close with difficulty to form the isoxazolone ring. In accord with these considerations, it appeared to us useless to attempt to obtain this oxime from the anhydride of methyl isoxazolone. Upon hydrolysis of the latter, and breaking of the ring, it would be able to form only the unstable anti methyloxime, which would close again with ease to give the isoxazolone ring. This, it appeared to us, would explain the unsuccessful attempts of Hantzsch to obtain the oxime of acetoacetic acid from the anhydride of methyl oxazolone.

1. The hydrolysis of the oxime of acetoacetic ester, in which, according to our supposition, there is already the necessary orientation of the oxime groups:



4. The hydrolytic cleavage of derivatives of methyl isoxazolone which contain a bivalent substituent in position 4. The presence of such a substituent should, according to our assumption, facilitate the rotation of the oxime group [7], if it is possible to break the isoxazolone ring:



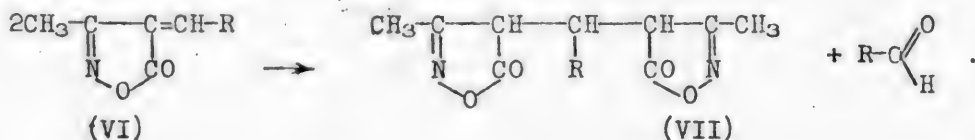
1924

For the preparation of the oxime of acetoacetic acid by the second method, we added to an aqueous solution of the sodium salt of acetoacetic acid the computed amount of hydroxylamine hydrochloride. After 3 or 4 days, a precipitate of the oxime of acetoacetic acid formed (short prisms). This was filtered off. Upon further standing of the filtrate, the separation of the anhydride of methyl isoxazolone took place (fine needles), mixed with the oxime of acetoacetic acid. The formation of the anhydride of methyl isoxazolone showed that the action of hydroxylamine on acetoacetic acid gave, in addition to the syn methyloxime (chief direction) a small amount of the anti methyloxime (side reaction), which was capable of closing to give the isoxazolone ring.

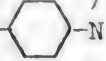
In the reaction of diketene with an aqueous solution of hydroxylamine (third method), there took place, as in the preceding case, the formation of two products, which precipitated out after long standing of the reacting solution. First there precipitated the oxime of acetoacetic acid, and then there began the separation of the anhydride of methyl isoxazolone.

As the starting material for the preparation of the oxime of acetoacetic acid by the fourth method, we chose 4-isopropylidene-3-methyl-isoxazolone, which under the action of aqueous alkali was able to split off acetone [8]. The isopropylidene-methylisoxazolone was boiled with the computed amount of dilute aqueous alkali (0.5 N KOH). The solution was cooled and acidified with hydrochloric acid. On the following day, there began the separation of a crystalline precipitate of the oxime of acetoacetic acid. After 3 or 4 days, the precipitate was filtered off and recrystallized from alcohol.

We studied the action of alkali on 4-isopropylidene-3-methylisoxazolone as well as on the other isoxazolone derivatives which had a semicyclic ethylene bond in position 4; during this, we observed that these compounds behaved differently, depending on the character of the substituent attached to position 4. Under the action of alkali on 4-benzylidene-3-methylisoxazolone and on p-dimethylaminobenzylidene-3-methylisoxazolone, even prolonged boiling split off only half the amount of aldehyde, in accordance with the equation:

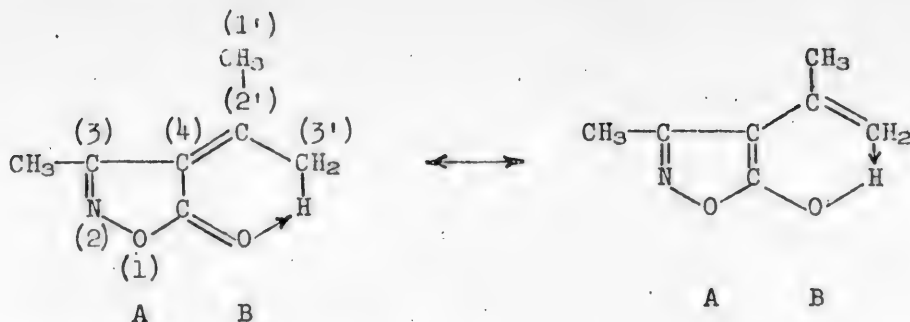


1. In the case where R was C₆H₅, the compound (VII) which formed showed considerable stability, and upon acidification, precipitated out of solution [7].

2. In the case where R equaled , compound (VII) was stable only in alkaline solution, and upon acidification, decomposed with the formation of compound (VI).

3. Under the action of alkali, all the acetone split off from 4-isopropylidene-3-methylisoxazolone. We boiled a sample of this compound with the computed amount of dilute alkali (0.5 N KOH), collected the distillate, and in it found almost the theoretical amount of acetone. The alkaline solution which remained did not contain the anhydride of methyl isoxazolone. After acidification, as already indicated, there precipitated only the oxime of acetoacetic acid. We may conclude from this that under the action of alkali there apparently takes place first a rupture of the isoxazolone ring, and then, the cleavage of the acetone.

It is possible that this is to be explained by the presence of a hydrogen bond in the molecule of 4-isopropylidene-3-methylisoxazolone (cf. [8]).

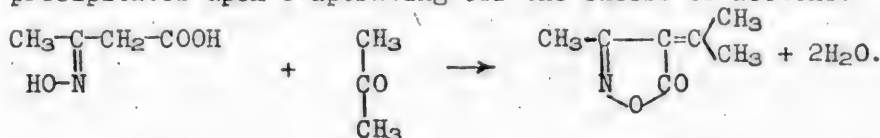


The presence of the six-membered ring (B) with a hydrogen bond would increase the stability of the 4—2' bond, which is here no longer a genuine double bond.

The Properties of the Oxime of Acetoacetic Acid

The oxime of acetoacetic acid, or β -hydroximinobutyric acid, is a solid, crystalline substance. When recrystallized from alcohol (6 volumes) it is in the form of fine, short prisms, with m.p. 105-105.5° (uncorrected). It is difficultly soluble in cold water. It dissolves in boiling water with some decomposition, so that the solution acquires a brownish color, and upon cooling, crystals of the oxime of acetoacetic acid precipitate out of it with slightly lowered melting point (102-103°). It is insoluble in benzene, chloroform, ether, and ethyl acetate. The oxime of acetoacetic acid dissolves in alkali in the cold with a yellowish color. Upon acidification, the solution becomes colorless, and from it there precipitates only slowly, sometimes only after rubbing with a stirring rod, a white precipitate of the unchanged oxime of acetoacetic acid in the form of crystalline flocs. (Under these conditions, the anhydride of methyl isoxazolone precipitates at once, and has the form of small fine needles). In the presence of phenolphthalein, it can easily be titrated with alkali, as a monobasic acid with a molecular weight of 117. (The anhydride of methyl isoxazolone is a monobasic acid with a molecular weight of 180). The dissociation constant, determined by a potentiometric method, is approximately equal to $5 \cdot 10^{-6}$ at 16°, while for the anhydride of methyl isoxazolone it is approximately equal to $5.6 \cdot 10^{-4}$ at 20° [9], and as measured by us at 16°, equals $6.3 \cdot 10^{-4}$.

Upon heating with dilute mineral acid, the oxime of acetoacetic acid is decomposed to give acetone, hydroxylamine, and carbon dioxide. This reaction takes place quantitatively (cf. experimental section). Upon boiling in a solution of acetone, the oxime of acetoacetic acid gives 4-isopropylidene-3-methylisoxazolone, which precipitates upon evaporating off the excess of acetone:



Upon careful solution in glacial acetic acid (in 6 volumes), the oxime of acetoacetic acid does not decompose, and upon dilution of the cold solution with water, it slowly crystallizes out unchanged. If, however, the solution in glacial acetic acid is heated to boiling, then upon cooling and diluting with water, there quickly forms a precipitate of 4-isopropylidene-3-methylisoxazolone.

Upon gentle heating, the oxime of acetoacetic acid dissolves in an aqueous solution of sodium nitrite to give a dark red solution of the sodium salt of 4-isonitroso-3-methylisoxazolone:



When the solution was acidified, a precipitate of 4-isonitroso-3-methylisoxazolone formed.

The oxime of acetoacetic acid condenses with p-dimethylamino benzaldehyde upon heating with a solution of the latter in dilute hydrochloric acid. This results in the formation of a red precipitate of p-dimethylamino benzylidene methyl isoxazolone, with the theoretical yield.

The sodium salt of the oxime of acetoacetic acid reacts with aqueous solutions of the salts of several heavy metals to give characteristic precipitates: with silver nitrate it forms a white precipitate which quickly darkens in the light; with mercuric chloride, it gives a voluminous white precipitate; with copper sulfate, a green-brown precipitate; with ferric chloride, a red-brown precipitate; with ferrous sulfate, an orange precipitate.

The properties of the oxime of acetoacetic acid we obtained, as described above, plus its elementary composition, its molecular weight, and the different chemical transformations show with complete clarity that this substance, both in the free form, as well as when dissolved or in the form of its salts, differs from the anhydride of methyl isoxazolone obtained by Hantzsch, and is not transformed into the latter in any of the reactions we have investigated. In contrast to the anhydride of methyl isoxazolone, the oxime of acetoacetic acid contains an active methylene group, because of which it also condenses with such compounds as acetone, nitrous acid, and p-dimethylamino benzaldehyde. In these reactions, the oxime of acetoacetic acid as was to be expected, shows a similarity to the previously known oxime of acetoacetic ester: upon the introduction of a bivalent substituent in place of the two hydrogens of the active methylene group, both of these substances close the isoxazolone ring, with the formation of a molecule of water or ethyl alcohol, respectively.

This gives us the justification to ascribe to the oxime of acetoacetic acid the structure of the syn methyloxime. At the same time, this is a confirmation of the assumption we had previously made [7] concerning the role of the spatial factor in the closure of the isoxazolone ring and of the connection between the ease of the syn-anti transformation and the mesomerism of the molecule of the substituted oxime of acetoacetic acid which contains a bivalent substituent in the active methylene group.

EXPERIMENTAL

A. The Preparation of the Oxime of Acetoacetic Acid

The action of hydroxylamine on acetoacetic acid. At room temperature, a solution of 5.7 g of caustic potash in 50 ml of water was added to 13 g of acetoacetic ester. After a day, the solution was extracted with ether (twice with 2 ml portions of ether) in order to remove the remaining drops of unsaponified acetoacetic ester. To the aqueous solution of the potassium salt of acetoacetic acid thus obtained, which had an alkaline reaction to phenolphthalein, there was added at room temperature 7 g of hydroxylamine hydrochloride. The transparent solution obtained, which had an acid reaction to Congo red, was allowed to stand. After 3 or 4 days, the separation of a crystalline precipitate began in the form of fine prisms. After an additional 2 or 3 days the precipitate was filtered off, washed with cold water and cold alcohol, and dried in a desiccator. The amount of precipitate was 1.4 g, the m.p. 102-103°. After an additional 4 or 5 days, an additional 0.3 to 0.4 g of precipitate of the oxime of acetoacetic acid came out of the brown filtrate. After recrystallization from 5 to 6 volumes of alcohol, 1.2 to 1.5 g of the pure oxime of acetoacetic acid was obtained, m.p. 104-105° (uncorr.). This amounted to 9 or 10% of the theoretical yield. Upon further standing (10 to 15 days), the filtrate gave a precipitate (1 to 1.3 g) which consisted predominantly of needle-shaped crystals of the anhydride of

methyl isoxazolone, which in unrefined form melted with decomposition at a temperature from 148-150° to 158-160°. After recrystallization from chloroform, it had m.p. 169-170° (with decomposition).

The action of hydroxylamine on diketene. To a solution of 1.5 g of hydroxylamine hydrochloride in 10 ml of water there was added drop by drop approximately 2 ml of a 25% solution of caustic soda, until there was a pale rose color with phenolphthalein. To this solution there was added at once 2 g of diketene (94% purity). At first, during stirring, the diketene was in the form of separate drops, then it went into solution, the process being accompanied by the evolution of heat (temperature about 80°). The solution, which had become orange-brown, was quickly cooled by a stream of water from the pipes and allowed to stand at room temperature. After 10 to 13 days, the crystals which had precipitated from the solution were filtered off, washed with water, and dried in a desiccator. The amount was 0.7 g, the m.p. 104-105°. The yield was 27.7% of the theoretical, computed on the basis of the hydroxylamine hydrochloride. After recrystallization from alcohol, 0.4 g of material was obtained (16% of theory), m.p. 105-105.5° (uncorrected). After 10 to 12 more days, a precipitate formed in the filtrate in the form of long needles, 0.3 g in amount. After recrystallization from 15 ml of chloroform, the precipitate melted with decomposition at 169-170°. It was the anhydride of methyl isoxazolone.

The hydrolysis of the oxime of acetoacetic ester. To 3 g of the oxime of acetoacetic ester, a 0.5 N solution of caustic potash was added until there was an alkaline reaction to phenolphthalein (44 ml). The solution was boiled for 1 hour with a reflux condenser, and cooled. It was acidified with concentrated hydrochloric acid (3 ml). After 3 to 4 days, the crystalline precipitate which had formed was filtered off, washed with water, and dried at 50 to 60°. The yield was 0.1 g, i.e., 10% of the theoretical. The substance, after recrystallization from 6 to 7 volumes of alcohol, had m.p. 104-105° (uncorrected).

Upon long storage, the wet oxime of acetoacetic ester also underwent partial saponification. Thus, upon standing in a sealed flask at room temperature for 5 to 6 weeks, the wet oxime of acetoacetic ester was converted into a dark brown, tarry, semisolid mass. It was washed with cold alcohol and then crystallized from hot alcohol to which animal charcoal had been added. The white crystalline precipitate which was obtained had m.p. 102-103° (uncorrected). A mixed test of this with the oxime of acetoacetic acid obtained by one of the methods given above showed no depression of the melting point. The yield did not exceed 5% of the theoretical.

The action of alkali on isopropylidene methyl isoxazolone. 2.8 g of isopropylidene methyl isoxazolone was dissolved in 44 ml of a half normal solution of caustic potash. The solution, which was alkaline to phenolphthalein, was boiled for 1 hour with a reflux condenser. After cooling, the solution was acidified with concentrated hydrochloric acid and allowed to stand at room temperature. Even by the following day, a precipitate began to form in the solution. After 3 or 4 days, the precipitate was filtered off, washed with water, and dried in a desiccator. The amount was 0.9 g, i.e., 38% of the theoretical, the m.p. 102-103°. After recrystallization from 5 to 6 volumes of alcohol, the m.p. was 104-105° (uncorrected).

The quantitative determination of the acetone split off. A sample of 0.7 g of isopropylidene methyl isoxazolone (0.005 mole) was dissolved in 11 ml of 0.5 N caustic potash solution, and 30 ml of water was added. The solution was distilled from a Wurtz flask with a direct condenser. About 30 ml of distillate was collected, and an additional 30 ml of water was added to the flask and 20 to 30 ml more was distilled off. The content of acetone was determined in the distillate [10]. For this purpose, 5 ml of a 20% solution of hydroxylamine hydrochloride

was added to the distillate, and titrated with a 0.1 N solution of caustic potash using Bromothymol blue. The titration required 47.5 ml of alkali, which corresponded to 95% of the theoretical amount of acetone.

B. Determination of the Composition and Molecular Weight of the Oxime of Acetoacetic Acid

0.1066 g substance: 0.1628 g CO₂; 0.1468 g H₂O.

0.0734 g substance: 7.6 ml N₂ (22°, 758 mm).

Found %: C 41.6; H 5.90; N 11.95.

C₄H₇O₃N. Computed %: C 41.02; H 5.98; N 11.96.

Titration of the oxime of acetoacetic acid with alkali

0.1156 g substance: 9.85 ml of 0.1 N NaOH consumed

Found: equiv. 117.4.

C₄H₇O₃N. Computed: equiv. 117.

Potentiometric titration.

0.1140 g of the substance was dissolved in 25 ml. of 0.1 N NaOH ($T_{\text{NaOH}} = 0.004021$) and titrated with 0.1 N HCl ($T_{\text{HCl}} = 0.003720$) at 16° with a glass electrode. The results of the titration are presented in Table 1 and in Figure 1.

TABLE 1

Amount of HCl (ml)	mV	Amount of HCl (ml)	mV	Amount of HCl (ml)	mV	Amount of HCl (ml)	mV
0	100.0	8	98.0	16	72.0	24	39.0
1	100.0	9	97.5	17	63.0	25	33.0
2	100.0	10	97.0	18	58.0	26	26.5
3	100.0	11	97.0	19	54.0	27	23.5
4	100.0	12	96.0	20	50.0	28	22.0
5	100.0	13	95.0	21	47.0	29	21.0
6	99.5	14	93.0	22	44.5	30	20.5
7	99.0	15	86.5	23	42.5	31	20.0

The transition points were at 15.6 ml (pH 9.9) and 25.1 ml (pH 3.5). The titration required $25.1 - 15.6 = 9.5$ ml HCl, and therefore M equaled 117.7 (computed for C₄H₇O₃N, M 117).

The dissociation constant computed from the curve equaled $5 \cdot 10^{-8}$ at 16°.

During the titration, the yellow color of the solution became more intense as the pH was decreased from 12 to 10, and then the solution was gradually decolorized upon further acidification to pH 3.5. The solution remained transparent throughout.

The potentiometric titration of the anhydride of methyl isoxazolone, carried out under the same conditions, gave a curve with only a single transition point at pH 7.6. The dissociation constant computed from this curve was equal to $6.3 \cdot 10^{-4}$ at 16°, and the molecular weight was 182 (from the formula C₈H₈O₃N₂ it should equal 180). During the

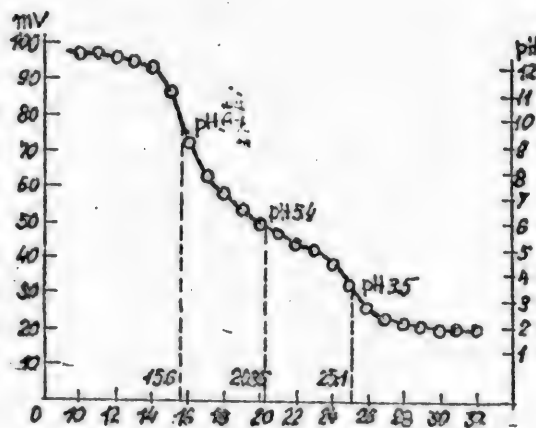


Fig. 1. Titration of the oxime of acetoacetic acid.

titration, the solution remained colorless. At pH 3, the formation of a precipitate took place. Table 2 and the titration curve (Fig. 2) are given below. A sample of 0.3380 g was dissolved in 25 ml of 0.1 N NaOH ($T_{\text{NaOH}} = 0.00390$) and titrated with 0.1 N HCl ($T_{\text{HCl}} = 0.00362$) at 16°.

TABLE 2

Amount of HCl (ml)	mV	Amount of HCl (ml)	mV	Amount of HCl (ml)	mV	Amount of HCl (ml)	mV
0	105	6.5	57.5	14	34.0	22	28.5
1	105	7	47.5	15	34.0	23	27.0
2	105	8	39.0	16	33.5	24	26.0
3	105	9	35.5	17	33.0	25	24.5
4	103	10	34.0	18	32.5	26	23.0
5	96.0	11	32.5	19	31.5	27	22.5
5.5	89.5	12	35.0	20	31.0	28	22.5
6	73.0	13	34.0	21	30.0	29	22.5

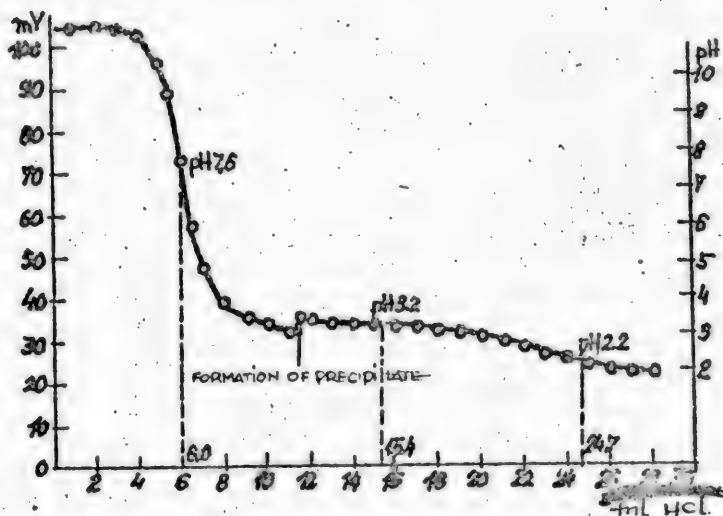


Fig. 2. Titration of the anhydride of methyl isoxazolone.

C. The Transformation of the Oxime of Acetoacetic Acid.

The action of dilute sulfuric acid. a) The determination of CO_2 . A sample of the oxime of acetoacetic acid (0.2448 g) was boiled with 50 ml of 0.1 N H_2SO_4 in a flask with a reflux condenser for 5 hours. The CO_2 evolved was absorbed in 0.1 N KOH (50 ml). In the titration, the excess of alkali required 29.5 ml of 0.1 N HCl, hence the amount of CO_2 equaled 98% of the theoretical.

b) The determination of acetone. To the solution which remained in the flask, 100 ml of water was added, and then 100 to 120 ml of liquid was distilled over, and the acetone determined in the distillate by the hydroxylamine method. Titration required 20 ml of 0.1 N KOH. Hence, the acetone content equalled 96% of the theoretical.

c) The determination of hydroxylamine. After the acetone had been driven off the liquid remaining in the distillation flask was titrated with 0.1 N KOH in the presence of phenolphthalein. The titration required 49.3 ml of 0.1 N KOH.

Then 2 drops of methyl orange was added to the titrated solution, and it was titrated with 0.1 N HCl until the formation of a rose color. This required 18.9 ml of 0.1 N HCl. Hence the content of hydroxylamine was 90% of the theoretical.

The reaction with acetone. 0.2 g of the oxime of acetoacetic acid and 20 ml of acetone were boiled with a reflux condenser for 1 hour. The solution was allowed to evaporate in the air. The residual material was dissolved for the purpose of purification in 1.5 to 2 ml of glacial acetic acid, filtered, and diluted with water. The precipitate which formed was washed with water and dried in a desiccator. There was obtained 0.2 g of material, m.p. 120-121°. A mixed test with isopropylidene methyl isoxazolone did not show any depression of the melting point.

The reaction with p-dimethylaminobenzaldehyde. 0.12 g of the oxime of acetoacetic acid was dissolved in 5 ml of alcohol, and 0.15 g of p-dimethylaminobenzaldehyde was added. Upon cooling, a red precipitate formed. It was filtered and washed. It weighed 0.22 g, melted with decomposition at 202-203°, and did not give a depression of the melting point in a mixed test with known p-dimethylaminobenzaldehyde-methyl isoxazolone.

The reaction with sodium nitrite. Upon careful heating of the oxime of acetoacetic acid with an aqueous solution of sodium nitrite, a dark red solution was formed. After acidification, a light precipitate formed from the solution, with m.p. 174° (with decomposition). It was identical with isonitroso methyl isoxazolone, and when mixed with the latter gave no depression of the melting point.

SUMMARY

1. The oxime of acetoacetic acid (β -hydroxyiminobutyric acid) is formed by the saponification of the oxime of acetoacetic ester, and also by the hydrolytic cleavage of isopropylidene methyl isoxazolone.
2. In addition, it is formed, together with the anhydride of methyl isoxazolone, by the action of hydroxylamine on acetoacetic acid, as well as by the interaction of hydroxylamine and diketene.
3. The current views, expressed by Hantzsch, to the effect that the anhydride of methyl isoxazolone upon solution in water or upon formation of a salt is transformed into the oxime of acetoacetic acid, are erroneous.
4. On the basis of the investigated properties of the oxime of acetoacetic acid, we must ascribe to it the spatial configuration of a syn methyloxime.

LITERATURE CITED

- [1] A. Hantzsch, Ber., 24, 498 (1891).
- [2] Beilstein, Handbook org. Chem., 27, 157 (1937).
- [3] R. Uhlenhuth, Ann., 296, 48 (1897).
- [4] P. Karrer, Course in Organic Chemistry, Gen. United Sci. Tech. Press, Moscow, 1938, p. 305-306.
- [5] V. Schlenk and E. Bergman, Organic Chemistry, v. I, United Sci. Tech. Press, Leningrad, 1936, p. 520.
- [6] J. Donlevy, E. Gilbert, J. Am. Chem. Soc., 59, 1072 (1937).
- [7] A. E. Porai-Koshits and N. V. Khromov, J. Gen. Chem., 10, 557 (1940).
- [8] N. V. Khromov and A. E. Porai-Koshits, J. Gen. Chem. 17, 1828 (1947).
- [9] Oliveri-Mandala, Gazz. chim. ital., 46, 1, 310 (1916).
- [10] Berl-Lunge, Chemico-Technical Methods of Investigation, v. III, No. 2, p. 272.

Received January 17, 1949.

INVESTIGATIONS IN THE DOMAIN OF ALIPHATIC-AROMATIC ACETYLENE GLYCOLS

I. THE PREPARATION AND PROPERTIES OF

SYMMETRICAL DIMETHYLDI-p-TOLYL-BUTYLDIOL (DI-p-TOLYL-2,5-HEXIN-3-DIOL-2,5)

A. I. Lebedeva and R. P. Riskina

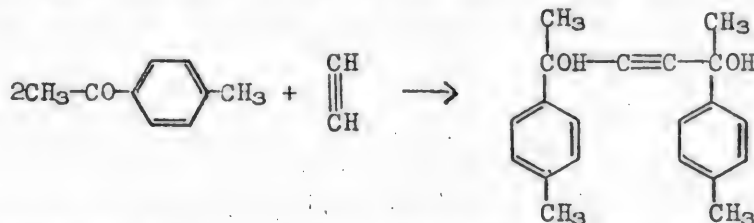
The A. E. Favorsky Laboratory of the A. A. Zhdanov Leningrad State University

Awarded the Order of Lenin

When dilute sulfuric acid acts upon methylphenylvinyl carbinol, there takes place, instead of the expected condensation of this ethylene alcohol in the manner of dimethylvinyl carbinol [1], its decomposition, with the formation of acetophenone and a polymer [2]. This difference in behavior with respect to dilute sulfuric acid may be explained by the presence in methylphenylvinyl carbinol of the phenyl radical; it would therefore be of interest to investigate the action of sulfuric acid on other aliphatic-aromatic ethylene alcohols, and in particular, on methyl-p-tolylvinyl carbinol.

The synthesis of methyl-p-tolylvinyl carbinol seemed possible to carry out by two methods: by the action of p-tolyl magnesium bromide on methylvinyl ketone, or, by starting with methyl-p-tolyl ketone and acetylene, obtaining methyl-p-tolylacetylenyl carbinol, and then hydrogenating the latter electrolytically under the proper conditions to give methyl-p-tolylvinyl carbinol. We chose the second method, and attempted to obtain methyl-p-tolylacetylenyl carbinol from methyl-p-tolyl ketone and acetylene by the method of Favorsky [3], developed for this case by Yu.S.Zalkind and H. Iremadze [4]. However, under the given conditions, we obtained chiefly a crystalline product, which turned out to be the acetylene glycol, dimethyldi-p-tolylbutindiol (di-p-tolyl-2,5-hexin-3-diol-2,5), and a liquid product, which consisted, apparently, of a mixture of methyl-p-tolylacetylenyl carbinol and methyl-p-tolyl ketone.

Thus, the main reaction could be expressed by the following equation:



The dimethyldi-p-tolylbutindiol, which was prepared by us in good yield (91.0%), after pressing out on a porous plate, melted at $109-115^\circ$ (not sharply). Upon crystallization from benzene, we obtained 2 fractions: the first, with m.p. $121-126^\circ$, and the second, which precipitated out only after the complete evaporation of the benzene, with m.p. $108-110^\circ$. Each fraction was recrystallized several times more from dilute alcohol (approximately 1:1). From the first fraction we isolated two kinds of crystals: shining platelets or scales with m.p. $122-123^\circ$ (II) and short solid little needles with m.p. $139-140^\circ$ (I). From the

second fraction, after several recrystallizations (also from dilute alcohol), there were obtained crystals in the form of long, shining, silky fibers, reminiscent of glass wool, with m.p. 113-114° (III).

The solubility of the crystals in benzene increased as the melting point decreased. Crystals (I), with m.p. 139-140°, dissolved only in hot benzene, and were precipitated from it almost quantitatively upon cooling. Crystals (III), with m.p. 113-114°, precipitated out only after complete evaporation of the benzene. The solubility of crystals (II), with m.p. 122-123°, was intermediate; however, in cold benzene it did not dissolve any too well. This relationship was not observed with regard to solution in dilute alcohol. A determination of the percentage content of carbons and hydrogen, as well as of the molecular weight (the first two fractions in dioxane, and the latter in benzene) and of the percentage content of hydroxyl by the Terentyev-Shcherbakova method showed that all three crystalline products obtained by us corresponded to an acetylene glycol with the general formula $C_{20}H_{22}O_2$. All three fractions failed to give a reaction for free acetylene hydrogen with an ammoniacal solution of silver oxide, but quickly decolorized a chloroform solution of bromine in the cold.

Dimethyldi-p-tolylbutindiol has 2 asymmetric carbon atoms, and therefore it might have been obtained by us in two stereoisomeric forms (the racemate and the meso form). At first we assumed that our preparation of a third crystal fraction of dimethylditolylbutindiol was an ortho or meta isomer. In our first experiments we obtained methyltolyl ketone by the Friedel-Crafts method, from which we might have expected the presence, together with methyl-p-tolyl ketone, of the ortho and meta isomers of this ketone. Therefore, we discarded the synthesis of methyl-p-tolyl ketone from toluene and acetyl chloride, and began to obtain it from p-toluidine. The action of cuprous bromide on p-toluidine transformed it into p-bromotoluene. Then, from p-tolylmagnesium bromide and acetaldehyde we obtained methyl-p-tolyl carbinol, which was then oxidized to give methyl-p-tolyl ketone. The methyl-p-tolyl ketone thus obtained was purified by its conversion into the semicarbazone.

After the decomposition of the semicarbazone, the pure methyl-p-tolyl ketone was made to condense with acetylene, by Favorsky's method. However, in this case too, after crystallization from benzene and dilute alcohol, we again obtained 3 fractions of glycols, with the melting points given above. Upon catalytic hydrogenation of the glycols over platinum black, all three glycols added somewhat more hydrogen than was computed theoretically for a single acetylene bond. Upon hydrogenation, glycol (I) added 102.0% hydrogen, glycol (II) 110.0%, and glycol (III) 108.5%. At the end of the hydrogenation, the velocity gradually decreased, and remained at some small, but almost constant, value. Apparently, here there began the reduction of the hydroxyl groups of the glycol. As a result of hydrogenation, we obtained in all three cases a nonhomogeneous product, which precipitated from dilute alcohol in the form of an oil. After numerous recrystallizations, it was possible to obtain from the oil a crystalline product, which was apparently the saturated glycol, dimethyldi-p-tolylbutandiol (di-p-tolyl-2,5-hexandiol-2,5). From the glycol (I), there was obtained dimethyldi-p-tolylbutandiol with m.p. 128-129°. A mixed test with the original glycol (I) melted at 112-114°. A determination of the percentage of hydroxyl showed the presence of two hydroxyl groups. The catalytic hydrogenation of glycols (II) and (III) under the same conditions as for glycol (I) gave one and the same saturated glycol, with m.p. 130-131°. A mixed test of this glycol with the original glycols melted in the following manner: with glycol (II), at 106-115°, and with glycol (III) at 96-99°. A mixed test with the hydrogenated glycol with m.p. 128-129° melted at 106-117°. The presence of two hydroxyls in the glycol with m.p. 130-131° was shown analytically (by the Terentyev-Shcherbakova method). Thus, upon hydrogenation, we obtained from the

three crystalline modifications of dimethyldi-p-tolylbutindiol two saturated glycols, which did not decolorize a chloroform solution of bromine, and were probably two stereoisomeric dimethyldi-p-tolylbutandiol (di-p-tolyl-2,5-hexandiol-2,5). The lower melting fraction, as well as the oil, obtained by the hydrogenation of the acetylene glycols, were not investigated in detail. The preparation from the three acetylene glycols of two saturated glycols also confirmed the absence in the acetylene glycol of other isomers in addition to the para isomer.

Further investigation showed that when glycol (II) was boiled in benzene it was partially transformed into glycols (I) and (III). Upon boiling in benzene, glycols (I) and (III) did not change. On the other hand, when equal weights of glycols (I) and (III) were boiled in dilute alcohol, glycol (II) was formed. Therefore, for the isolation of the glycols in pure form, it is absolutely necessary to carry out the first crystallization from benzene. Several attempts were made to obtain the glycols by crystallization from alcohol with preliminary recrystallization from benzene, but these attempts were unsuccessful. The glycols did not precipitate from 96% alcohol, while from dilute alcohol there precipitated an oil which hardened only after lengthy cooling and melted below 100°.

The three fractions of dimethyldi-p-tolylbutindiol which we had prepared differed from each other in melting point and solubility. This fact apparently indicated that we were here dealing with three modifications of two stereoisomeric forms of dimethyldi-p-tolylbutindiol. The presence of a greater number of modifications than was predicted by the generally accepted theory has long been known for various organic compounds. In the majority of cases, these compounds are aromatic derivatives of the ethylene series. However, among them are also such compounds, for example, as benzophenone [5]. The existence of these modifications is probably to be explained by the presence of finer configurational differences in the structure of the molecule than can be shown on the basis of the existing theories. It is of interest to note the fact that in all the data in the literature we could not find examples which indicated the possibility of existence of a greater number of modifications than theory predicted for compounds of the acetylene series. It is known that symmetrical dimethyldiphenylbutindiol exists in only two forms, as Dupont [6] has shown, and as we have verified. It is possible that the ability to form "superfluous" modifications exists in acetylene compounds in the presence of a more branched radical (aliphatic or aromatic) when there is the possibility of the existence of "rotation isomers". In further work, we propose to verify the correctness of the considerations we have expressed with other acetylene glycols containing branched radicals.

The liquid product with b.p. 88-92° (3 mm), obtained by us in several experiments together with the glycol, reacted with an aqueous solution of permanganate, decolorized bromine water, and gave a precipitate with an ammoniacal solution of silver oxide. All this indicated the presence in it of methyl-p-tolylacetylenyl carbinol. However, this product also reacted with semicarbazide, giving a precipitate of a semicarbazone which corresponded, with regard to melting point, to the semicarbazone of methyl-p-tolyl ketone. In order to determine the content of methyl-p-tolylacetylenyl carbinol in the liquid product, the latter was subjected to catalytic hydrogenation in the presence of platinum black. It added 55% of the hydrogen computed on the basis of one acetylene bond. Consequently, in the mixture we were investigating, there was about 55% of the acetylenyl alcohol, the remainder consisting of various saturated products, chiefly of the original methyl-p-tolyl ketone.

At present, experiments are being conducted on the improvement of the yield of methyl-p-tolylacetylenyl carbinol, its isolation in pure form, and its identification.

EXPERIMENTAL

The preparation of dimethyldi-p-tolylbutindiol. Methyl-p-tolyl ketone was prepared from p-toluidine by way of p-bromatoluene, p-tolyl magnesium bromide, and methyl-p-tolyl carbinol. Methyl-p-tolyl carbinol was oxidized to methyl-p-tolyl ketone, which was then transformed into the semicarbazone, which melted (from alcohol) at 202-203°. The semicarbazone was decomposed with dilute hydrochloric acid, and the ketone extracted with ether. After drying with potash and removal of the ether by distillation, the methyl-p-tolyl ketone distilled at 106-107.5° (17 mm); n_D^{20} 1.5338.

30 g of the methyl-p-tolyl ketone thus obtained was added, in 150 ml of ether, with stirring and the simultaneous passage of a current of acetylene, to a mixture which consisted of 60 g of caustic potash in 300 ml of ether, with cooling of the outside of the container with ice. The reaction was continued for 5 hours, and the reaction mixture was allowed to stand overnight, then decomposed with water while being cooled with ice containing salt. The ether layer was separated, saturated with carbon dioxide, dried with fused potash, and the ether driven off. The residue (16.4 g) crystallized upon standing in a vacuum desiccator. The dark crystalline mass was pressed free from oil on a porous plate and recrystallized from benzene. After the benzene had cooled, 8.9 g of crystals precipitated out, with m.p. 121-126°. After several crystallizations from dilute alcohol (approximately 1:1) the following two crystal fractions were obtained: (II) with m.p. 122-123° (3 g), shining scales or transparent platelets; (I), with m.p. 139-140°, (1.4 g), solid little needles.

Upon evaporating the benzene filtrate to dryness, crystals precipitated with m.p. 109-111°. After several recrystallizations from dilute alcohol, crystal fraction (III) was obtained with m.p. 113-114° (1.8 g) in the form of shining, silky fibers.

Analysis of the glycol with m.p. 139-140° (I):

0.0703 g substance: 0.2098 g CO₂; 0.0482 g H₂O.

0.0945 g substance: 0.2828 g CO₂; 0.0679 g H₂O.

Found %: C 81.37, 81.60; H 7.66, 8.03.

C₂₀H₂₂O₂. Computed %: C 81.60; H 7.53.

0.1180 g substance: 23.34 g dioxane: Δt 0.080°.

0.2018 g substance: 17.98 g dioxane: Δt 0.177°.

Found: M 290.7, 291.7.

C₂₀H₂₂O₂. Computed: M 294.4.

0.0478 g substance: 7.7 ml CH₄ (8.6°, 743 mm).

0.0740 g substance: 11.6 ml CH₄ (6.2°, 743 mm).

Found %: OH 11.30, 11.38.

C₂₀H₂₀(OH)₂. Computed %: OH 11.55.

The alcoholic solution of the glycol did not give a precipitate with an ammoniacal solution of silver oxide. The glycol decolorized a solution of bromine in chloroform.

Catalytic hydrogenation. 1.50 g substance: 0.5 g Pt, 50 ml C₂H₅OH. Hydrogenation was continued for 3 hours 40 min. 250 ml of H₂ was added (18.8°, 760 mm), 102.0% of the theoretical. C₂₀H₂₆O₂. Computed: 228.5 ml H₂.

The alcohol was driven off, and the glycol recrystallized from dilute alcohol. There was obtained 1.13 g of material, which melted at 128-129°. A mixed test with the original glycol melted at 112-114°. The glycol did not decolorize a chloroform solution of bromine.

0.1108 g substance: 12.8 ml CH₄ (20.1°, 760.7 mm).
Found %: OH 10.77.
C₂₀H₂₄(OH)₂. Computed %: OH 11.40.

Analysis of the glycol with m.p. 122-123° (II):

0.1255 g substance: 0.3760 g CO₂; 0.0877 g H₂O.
0.1049 g substance: 0.3144 g CO₂; 0.0690 g H₂O.
Found %: C 81.72, 81.75; H 7.81, 7.36.
C₂₀H₂₂O₂. Computed %: C 81.60; H 7.53.

0.2881 g substance: 24.47 g dioxane: Δt 0.185°.
0.1580 g substance: 19.50 g dioxane: Δt 0.125°.
Found: M 292.8, 297.6.
C₂₀H₂₂O₂. Computed: M 294.4.

0.1000 g substance: 17.2 ml CH₄ (19°, 756 mm).
0.0914 g substance: 14.2 ml CH₄ (17°, 755 mm).
Found %: OH 11.82, 11.01.
C₂₀H₂₀(OH)₂. Computed %: OH 11.55.

An alcoholic solution of the glycol did not give a precipitate with an ammoniacal solution of silver oxide. The glycol decolorized a chloroform solution of bromine.

Catalytic hydrogenation. 1.5 g substance: 0.5 g Pt, 50 ml C₂H₅OH. Hydrogenation was continued for 2 hours. 269 ml of H₂ was added (19°, 761 mm), 110.0% of the theoretical. C₂₀H₂₆O₂. Computed: 228.5 ml H₂.

The alcohol was driven off, and the glycol recrystallized from dilute alcohol. There was obtained 0.21 g of substance, which melted at 130-131°. A mixed sample with the original glycol melted at 106-115°, and a mixed sample with the glycol obtained from the hydrogenation of glycol (I) melted at 106-117°.

0.0544 g substance: 8.6 ml CH₄ (19°, 763 mm).
Found %: OH 11.06.
C₂₀H₂₄(OH)₂. Computed %: OH 11.40.

The glycol did not decolorize a chloroform solution of bromine. After the first portion of crystals had been precipitated, there remained an oil which partially crystallized after standing for several days. There was obtained 0.9 g of crystals, which melted at 104-117°.

Analysis of the glycol with m.p. 113-114° (III).

0.0945 g substance: 0.2843 g CO₂; 0.0630 g H₂O.
0.1001 g substance: 0.3020 g CO₂; 0.0673 g H₂O.
Found %: C 81.33, 81.60; H 7.46, 7.52.
C₂₀H₂₂O₂. Computed %: C 81.60; H 7.53.

0.0721 g substance: 23.90 g benzene: Δt 0.053°.
0.1374 g substance: 23.90 g benzene: Δt 0.100°.
Found: M 294.7, 297.8.
C₂₀H₂₂O₂. Computed: M 294.4.

0.0644 g substance: 10.2 ml CH₄ (22°, 763 mm).
0.0525 g substance: 9.0 ml CH₄ (23°, 763 mm).
Found %: OH 10.92, 11.72.
C₂₀H₂₀(OH)₂. Computed %: OH 11.55.

An alcoholic solution of the glycol did not give a precipitate with an ammoniacal solution of silver oxide. The glycol decolorized a chloroform solution of bromine.

Catalytic hydrogenation. 1.0 g substance: 0.5 g Pt, 50 ml C_2H_5OH . Hydrogenation was continued for 1 hour 50 minutes. Consumed 175 ml H_2 (19°, 768 mm). 108.5% of the theoretical. $C_{20}H_{26}O_2$. Computed: 152.4 ml H_2 .

The alcohol was driven off and the glycol recrystallized from dilute alcohol. There was obtained 0.8 g of a substance which melted at 130-131°. A mixed test with the original glycol melted at 96-99°. A mixed test with the glycol obtained from hydrogenation of glycol (I) melted at 105-117°. A mixed test with the preceding hydrogenated glycol gave no depression of the melting point. The glycol did not decolorize a chloroform solution of bromine.

0.0575 g substance: 9.3 ml CH_4 (21°, 762 mm).

Found %: OH 10.90.

$C_{20}H_{24}(OH)_2$. Computed %: OH 11.40.

Investigation of the mutual transformations of the dimethyldi-p-tolylbutin-diols. 1) 1 g of the glycol (I) with m.p. 139-140° was dissolved in 35 ml of benzene by boiling. After cooling, 1.0 g of crystals with m.p. 138-139° precipitated out. After recrystallization from dilute ethyl alcohol, 0.9 g of crystals precipitated out in the form of small needles with m.p. 139-140°. The residue after the evaporation of the benzene melted at 133-136°.

2) 1 g of glycol (III) with m.p. 113-114° was treated in the same manner with boiling benzene. After cooling of the benzene, at first nothing precipitated. After the benzene had been driven off on the water bath, 1 g of crystals with m.p. 113-114° remained. After recrystallization from dilute ethyl alcohol, 0.9 g of crystals were obtained in the form of shining silky fibers with m.p. 113-114°.

3) 3 g of glycol (II) with m.p. 122-123° was dissolved by boiling in 50 ml of benzene. After the benzene had been cooled, 2.40 g of crystals with m.p. 121-123° precipitated out. After recrystallization from dilute alcohol, 2 crystal fractions were obtained: 1) with m.p. 122-123° (1.7 g), 2) with m.p. 122-134° (0.6 g).

After the benzene had been driven off, an additional 0.7 g of crystals was obtained, with m.p. 109-114°. The 0.7 g was recrystallized from dilute alcohol, and again 2 fractions were obtained: 1) with m.p. 121-122° (0.2 g), 2) with m.p. 109-111° (0.4 g). The fraction with m.p. 109-111° was again recrystallized from dilute alcohol; m.p. 113-114°.

1.7 g of the crystals with m.p. 122-123° was again boiled in 28 ml of benzene. After the benzene had cooled, a precipitate formed (0.9 g), melting at 131-135°. The 0.9 g was recrystallized from dilute alcohol to give two fractions: 1) with m.p. 138-139° (0.5 g), 2) with m.p. 121-127° (0.3 g).

The residue, which precipitated after the evaporation of the benzene (0.75 g), melted at 109-113°. It was recrystallized from dilute alcohol, giving the following fractions: 1) with m.p. 122-123° (0.2 g), 2) with m.p. 109-111° (0.5 g). After several crystallizations from alcohol, the second fraction melted at 113-114°.

4) A mixture of 0.50 g of glycol (I) in the form of small needles and 0.50 g of glycol (II) in the form of silky fibers was recrystallized from dilute alcohol. 0.95 g of crystals was obtained in the form of shining scales with m.p. 122-123°. The residue of about 0.05 g melted at 121-122°. After 3 crystallizations from dilute alcohol, the scales melted at 122-123°. No lower or higher fractions were observed.

The preparation of methyl-p-tolylacetylenyl carbinol. 14.6 g of methyl-p-tolyl ketone in 60 ml of ether was added slowly, drop by drop, with stirring and simultaneous passage of a current of acetylene, to a mixture of 26 g of powdered caustic potash in 150 ml of ether, cooled from the outside with ice and water.

The decomposition of the alcoholate and the formation of the ethereal layer were carried out as before. After the ether had been driven off, 15.1 g of an oily substance was obtained, from which a few crystals with m.p. 120-121° precipitated. The main product was subjected to a fractional distillation in vacuum, and gave the following fractions (at 5 mm): b.p. 85-94° (6.6 g) and b.p. 94-100° (2.8 g). The crystalline residue in the flask was 1.5 g.

From this residue there was obtained, after recrystallization from benzene and alcohol, 3 crystal fractions: 1) with m.p. 139-140° (0.43 g), 2) with m.p. 122-123° (0.15 g), and 3) with m.p. 113-114° (0.20 g).

From 1 g of the fraction with b.p. 85-94° (5 mm) there was obtained 1.5 g of the semicarbazone, which melted at 202-203° from alcohol. The semicarbazone of methyl-p-tolyl ketone, according to the data in the literature [7], melts at 204-205°. The fraction with b.p. 94-100° at 5 mm was subjected to distillation, and again gave 2 fractions (at 3 mm): 1) 85-88° (0.5 g), 2) 88-92° (1.7 g); n_D^{20} 1.5340; d_4^{20} 1.006.

The fraction with b.p. 88-92° reacted in the cold with an aqueous solution of permanganate and gave a white precipitate with an ammoniacal solution of silver oxide.

The catalytic hydrogenation of the fraction with b.p. 88-92° at 3 mm. 1.7 g substance: 0.2 g Pt, 30 ml C_2H_5OH . The addition of hydrogen was continued in all for 35 minutes, then completely discontinued. 283 ml of H_2 was added (20°, 759 mm), 55% of theoretical. $C_{11}H_{18}O$. Computed: 476 ml H_2 .

After the alcohol had been driven off, 1.3 g of liquid was obtained. This did not react with an aqueous solution of permanganate and did not give a precipitate with an ammoniacal solution of silver oxide. Further investigations are being continued.

SUMMARY

1. The action of acetylene on methyl-p-tolyl ketone according to the method of Favorsky gave a good yield of the unknown glycol dimethyldi-p-tolylbutindiol (di-p-tolyl-2,5-hexin-3-diol-2,5), which was characterized.
2. Three crystalline modifications of dimethyldi-p-tolylbutindiol were isolated, possessing different physical properties.
3. The conditions for the transformation of the modification with intermediate melting point into the higher melting and the lower melting modifications, and vice versa, have been determined.
4. The catalytic hydrogenation of dimethyldi-p-tolylbutindiol gave 2-stereoisomeric forms of dimethyldi-p-tolylbutandiol (di-p-tolyl-2,5-hexandiol-2,5).

LITERATURE CITED

- [1] A.E.Favorsky and A.I.Lebedeva, J.Gen.Chem. 8, 879 (1938).
- [2] A.I.Lebedeva, J.Gen.Chem. 20, 407 (1950).
- [3] A.E.Favorsky, Author's certificate, No 31017.
- [4] Yu.S.Zalkind and N.Iremadze, J Gen.Chem. 18, 1554 (1948).
- [5] K. Schaum, Chem. Zeitung., 38, 257 (1914); Ann., 411, 161 (1916).
- [6] Dupont, Comptes rend., 150, 1121 (1910).
- [7] R.Sorge, Ber., 35, 1070 (1902); K. Auwers and G.Keli, Ber., 38, 1711 (1905).

Received November 29, 1948.

See CB translation p. 431 ff.

THE SULFONATION AND SULFONIC ACIDS OF ACIDOPHOBIC COMPOUNDS

XII. THE SULFONATION OF STYRENE AND OF o-PHENYLBUTADIENE

A. P. Terentyev and A. V. Dombrovsky

Laboratory of Organic Chemistry of Moscow State University

In a review of the sulfonation of acidophobic compounds, one of us in 1947 [1] indicated styrene among the compounds which could be sulfonated by means of pyridine-sulfotrioxide. In the present communication we shall give a detailed description of this reaction. The ethylene group of styrene is characterized not only by the usual addition reactions, but also by its tendency to substitute the hydrogen in the ω -position by halogen, the nitro group, and the sulfonic acid group. According to the data of the investigations of Kharasch and his coworkers [2], when N,N'-dibromosulfonamides act on styrene, ω -bromostyrene, $\text{C}_6\text{H}_5\text{-CH=CH-Br}$, is obtained. Jordan [3] noted that under the conditions for the bromination of styrene by the method of Kaufmann, that is, with bromine in methyl alcohol which has been saturated with sodium bromide, along with the addition of bromine to the double bond, there is the formation of HBr and $\text{C}_6\text{H}_5\text{-CH=CHBr}$. ω -Nitrostyrene, $\text{C}_6\text{H}_5\text{-CH=CHNO}_2$, was apparently first obtained by Simon as far back as 1839 [4] by the careful distillation of styrene with nitric acid. For a detailed investigation of the properties and methods of preparation of nitrostyrene we must refer to the nineties of the past century, although even in 1873 P. Alekseev [5] investigated the chief properties of nitrostyrene. It is probable that he also developed a method for the preparation of this substance. Not only the direct nitration of styrene, but the action of fuming nitric acid [6] or of nitric oxides [7] on cinnamic acid gives ω -nitrostyrene and its derivatives.

Concentrated sulfuric acid converts styrene into a tarry material. The sulfonation of styrene without tarring was first carried out by A. Quillico and E. Fleischner [8] in 1928. As a sulfonating reagent they used sulfamic acid, $\text{NH}_2\text{SO}_3\text{H}$. The authors showed that this resulted in the formation of the ammonium salt of ω -styrenesulfonic acid. However, they did not report the yield of the latter.

Suter [9] and his coworkers used for the purpose of sulfonation the product of the addition of sulfur trioxide to dioxane - dioxane-sulfotrioxide. By the action of this reagent at 0 - 5°, they were first able to obtain about 23% of the theoretical yield of styrenesulfonic acid. In 1948, Bordwell and Randestvedt [10], using the same reagent for sulfonation at 55°, obtained up to 75% of theory of styrenesulfonic acid. Along with this, they also obtained as products of the reaction several addition products of sulfur trioxide and styrene. We must note also that in 1939, Kharasch [11] and his coworkers investigated the reaction of styrene with ammonium bisulfite in the presence of oxygen. The authors observed, among other products, styrenesulfonic acid.

The pyridine-sulfotrioxide used by us has a number of advantages over the

other sulfonating agents for compounds that tar easily. It is simple to obtain, keeps indefinitely in the absence of moisture, and is completely stable up to 200°. This distinguishes it favorably from the easily altered dioxane-sulfotrioxide. Sulfamic acid is a less vigorous sulfonating agent, and it is difficult to separate during the subsequent treatment of the products of reaction.

We carried out the sulfonation of styrene by heating it in a sealed tube up to 100° for 10 hours with twice the theoretical amount of pyridine-sulfotrioxide in a solution of dichloroethane. After treatment of the product of the reaction, the barium salt of the sulfonic acid was separated in quantitative yield (96%).

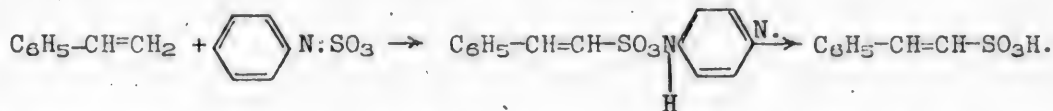
The structure of this acid as an ω -styrenesulfonic acid was shown by its transformations. Upon oxidation with permanganate, benzoic acid was formed, and fusion with sodium formate gave cinnamic acid. The action of bromine on aqueous solutions of styrenesulfonic acid and its salts led to the substitution of bromine for the hydrogen in the α -position with respect to the sulfonic acid group:



A similar phenomenon was noted by Kohler [12] in his investigation of ethylene-sulfonic acid, $\text{CH}_2=\text{CH-SO}_3\text{H}$, in which the sulfonic acid group is also at a double bond, and the reaction with bromine gives $\text{CH}_2=\text{CH-Br-SO}_3\text{H}$.

On the basis of these properties, Bordwell and Randestvedt [10] suggested a method for the quantitative determination of styrenesulfonic acid by titration of its aqueous solutions with bromine. In this connection, we must note that in *p*-nitro- ω -nitrostyrene, $\text{NO}_2\text{-C}_6\text{H}_4\text{-CH=CH-NO}_2$, the hydrogen which is in the α -position to the nitro group can be substituted by bromine and even by sodium [13]. This sort of property of unsaturated sulfonic acids containing a sulfonic acid group next to a double bond may be explained by the fact that the hydrogen under the influence of the sulfonic acid group becomes mobile, and becomes capable of an exchange reaction with a halogen.

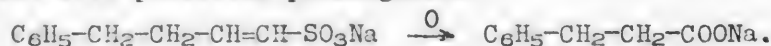
Thus, we have shown that the sulfonation of styrene by means of pyridine-sulfotrioxide takes place according to the equation:



α -Phenylbutadiene, $\text{C}_6\text{H}_5\text{-CH=CH-CH=CH}_2$, the second subject of our investigation, has been considerably less investigated than styrene. The condensation of this hydrocarbon takes place considerably more rapidly than that of the majority of other diene hydrocarbons. The polymerization of phenylbutadiene, and the structure of its polymers have been investigated by S.V. Lebedev and Ivanov [14]; they found that at a temperature of 150°, after a day, almost complete polymerization took place. The kinetics of the polymerization of phenylbutadiene have been investigated by one of us with Zegelman [15], by means of a method we developed for the diazometric determination of diene hydrocarbons. During this we showed that even at 100°, phenylbutadiene was polymerized to the extent of 87% after 10 hours. Except for the azo-conjugation reaction noted in this work, up to the present time the literature contains no descriptions of examples of the direct substitution of this easily altered hydrocarbon.

We were able, with the use of pyridine-sulfotrioxide, to sulfonate phenylbutadiene with a yield 50% of theory under conditions similar to those for the sulfonation of styrene, that is, at 100°, and a period of 4 hours. The barium and sodium salts of phenylbutadienesulfonic acid that were obtained were white crystalline substances, not so soluble in water as the corresponding salts of ω -styrenesulfonic acid. They decolorized potassium permanganate and bromine

water, and added 4 atoms of hydrogen in the presence of nickel catalyst. The position of the sulfonic acid group in the side chain was shown by us by oxidation with permanganate. This split off the sulfonic acid group completely in the form of sulfate ion, and gave benzoic acid. In order to locate the sulfonic acid group precisely in the side chain, the sodium salt was reduced with nickel which had been prepared by the Raney method. It added only 2 atoms of hydrogen. The dihydrosulfonic acid of phenylbutadiene obtained, $\text{C}_6\text{H}_5\text{-CH}_2\text{-CH}_2\text{-CH=CH-SO}_3\text{H}$, was oxidized with potassium permanganate:



This split off the sulfonic acid group in the form of sulfate ion, and the hydrocinnamic acid formed was identified by the analysis of its silver salt.

Consequently, in the case of phenylbutadiene, as well as in the case of styrene, sulfonation by the use of pyridine-sulfotrioxide takes place in a single way, that is, the sulfonic acid group is at the end of the side chain, substituting the hydrogen in the ω -position.



EXPERIMENTAL

The sulfonation of styrene. 5.6 g (0.053 mol.) of styrene, 17.6 g (0.11 mol.) of pyridine-sulfotrioxide, and 6 ml of dichloroethane were heated for 10 hours in a sealed tube at 100° . The fused sulfonated mass was treated with a concentrated solution of ammonia. In the dichloroethane layer that separated out, there was, in addition to the pyridine, a small amount of the ammonium salt of styrenesulfonic acid, which remained behind after the distillation of the volatile solvents. The salt was added to the aqueous ammoniacal solution. The latter was treated with baryta in order to remove sulfates and ammonia. The excess of baryta was precipitated with carbon dioxide. The removal of the barium salt of styrenesulfonic acid from the mixture of sulfates and barium carbonate required extraction with hot water, as the salt was difficultly soluble in cold water. 13 g of the barium salt was obtained. It was soluble in hot water, insoluble in alcohol and the usual organic solvents.

5.969 mg substance: 2.753 mg BaSO_4 .

Found %: Ba 27.14.

$(\text{C}_8\text{H}_7\text{O}_3\text{S})_2\text{Ba}$. Computed %: Ba 27.27.

The potassium and sodium salts of styrenesulfonic acid were prepared by precipitation from the boiling solution of the barium salt with the corresponding carbonate solutions.

5.849 mg substance: 2.034 mg Na_2SO_4 .

Found %: Na 11.26.

$\text{C}_8\text{H}_7\text{O}_3\text{SNa}$. Computed %: Na 11.16.

6.344 mg substance: 1.991 mg K_2SO_4 .

Found %: K 14.08.

$\text{C}_8\text{H}_7\text{O}_3\text{SK}$. Computed %: K 13.97.

The silver salt of styrenesulfonic acid was apparently unstable, as when it was precipitated from solutions of the potassium or sodium salts with silver nitrate, the white precipitate which was first formed quickly darkened.

The free styrenesulfonic acid was formed by the precipitation of the barium salt with the computed amount of dilute sulfuric acid, and careful concentration. It was a syrupy mass, which crystallized after long standing over sulfuric acid in


a vacuum desiccator. The melting point of the crystals was 54°; above 120°, charring took place.

Fusion with sodium formate. 4 g of the sodium salt of styrenesulfonic acid was ground with 8 g of anhydrous sodium formate, and the powder was poured into an iron crucible and carefully heated in the gentle flame of a gas-burner with constant stirring. The melt was dissolved in a small amount of water (about 15 ml), filtered, and acidified with hydrochloric acid. The evolution of sulfur dioxide was observed, and a white precipitate formed. The precipitate, after being recrystallized from hot water, melted at 132°, and did not give a depression of the melting point in a mixed test with cinnamic acid.

Oxidation with potassium permanganate. 2 g of the sodium salt of styrenesulfonic acid was dissolved in 30 ml of water, made slightly alkaline with caustic soda, and the solution was brought to the boiling point. To the boiling mixture there was added in small portions a 1% solution of potassium permanganate until a weak color remained. At the beginning of the oxidation the odor of benzaldehyde was detected. After the removal of the manganese dioxide, the filtrate was evaporated to dryness on the water bath. It was identified by its melting point of 122.5°, and by a mixed melting point test with benzoic acid.

The acid chloride of styrenesulfonic acid. 4 g of the dry sodium salt of styrenesulfonic acid was treated at ordinary temperature with double the amount of phosphorus pentachloride. Toward the end of the reaction, the mixture was heated slightly on the water bath, and then poured into ice water. The product that precipitated out was washed and recrystallized from benzene. It then had m.p. 88°, which is very close to the figure given in the literature (m.p. 89-89.5°).

The amide of styrenesulfonic acid. 1.5 g of the acid chloride of styrenesulfonic acid was heated for an hour with 30 ml of ethyl alcohol saturated with gaseous ammonia. After the alcohol had been driven off, and the reaction product washed with cold water, it was recrystallized twice from hot water. The crystals obtained melted at 142°. According to the data of Kharasch [11], the amide melts at a temperature of 143°.

The preparation of the N-substituted amide: $\text{C}_6\text{H}_5\text{CH}=\text{CHSO}_2\text{HN}$ . 1.5 g

of the acid chloride of styrenesulfonic acid was heated for two hours on the water bath with a reflux condenser with 1 g (an excess) of α -aminopyridine and 1 ml of pyridine in benzene solution. The precipitate which formed was washed, after removal from the organic solvents, with a dilute solution of sulfuric acid, and then with cold water. The α -aminopyridide of styrenesulfonic acid was a white crystalline substance with m.p. 185°.

5.635 mg substance: 0.547 ml N_2 (17°, 740 mm).

4.915 mg substance: 0.473 ml N_2 (18°, 740 mm).

Found %: N 11.13, 10.99.

$\text{C}_{13}\text{H}_{12}\text{O}_2\text{N}_2\text{S}$. Computed %: N 10.72.

The action of bromine. 2 g of the sodium salt of styrenesulfonic acid was dissolved in a small amount of water and treated with bromine water until there was a yellow color which did not disappear. The solution was evaporated to dryness on the water bath, the vapors of hydrogen bromide being carried away in a current of air. The residue was recrystallized from alcohol. There was obtained 1.9 g of a crystalline substance.

0.2648 g substance: 0.1762 g AgBr.

Found %: Br 28.32.

$\text{C}_8\text{H}_6\text{O}_3\text{SBrNa}$. Computed %: Br 28.03.

After acidification benzoic acid precipitated out of the solution.

The sulfonation of α -phenylbutadiene. Phenylbutadiene was obtained by a method described by Grummitt and Becker [18] with modifications added by A.P. Terentyev [15]. The boiling point of phenylbutadiene was 73-78° at 8-10 mm; n_D^{20} 1.6092, d_4^{18} 0.9920, which corresponded to the data in the literature.

5 g (0.04 mol) of freshly distilled phenylbutadiene was dissolved in 16 ml of dichloroethane, 0.3 g of m-dinitrobenzene was added as a stabilizer, and the solution was heated in a sealed tube with 18.2 g (0.12 mol.) of pyridine-sulfoxide at 100° for 4 hours. The fused sulfonated mass had a brown color. It was treated exactly like the sulfonated mass in the case of the sulfonation of styrene. 5.3 g of the barium salt (49.6%) were obtained. The rest of the phenylbutadiene was converted into a polymer.

2.683 mg substance: 1.124 mg BaSO₄.

Found %: Ba 24.65.

(C₁₀H₉O₃S)₂Ba. Computed %: Ba 24.71.

The sodium salt was obtained by precipitation with a solution of soda from the boiling solution of the barium salt. It was in the form of white crystals, readily soluble in water.

2.796 mg substance: 0.832 mg Na₂SO₄.

Found %: Na 9.64.

C₁₀H₉O₃SNa. Computed %: Na 9.90.

Oxidation with potassium permanganate. 1 g of the sodium salt of phenylbutadienesulfonic acid was oxidized in the same way as the sodium salt of styrenesulfonic acid. The benzoic acid obtained had m.p. 121°. A mixed melting point test with benzoic acid gave no depression.

Reduction over nickel, according to Raney. A solution of 1 g (0.0043 mol.) of the sodium salt was placed in a duck-shaped vessel with 3 g of nickel, prepared according to Raney. Upon shaking for 3 hours at room temperature 192 ml (0.0086 mol.) of hydrogen was absorbed. Further absorption of hydrogen was cut short. The solution of the reduced salt decolorized neither a solution of potassium permanganate nor one of bromine water.

4.343 mg substance: 1.263 mg Na₂SO₄.

Found %: Na 9.42.

C₁₀H₁₃O₃SNa. Computed %: Na 9.73.

The reduction of one double bond, and the oxidation of the hydrogenation products. An aqueous solution of 1 g (0.0043 mol.) of the sodium salt was shaken in a duck-shaped vessel in a rocking machine over nickel, and was permitted to absorb only 96 ml (0.0043 mol.) of hydrogen. The solution of this salt decolorized potassium permanganate, splitting off the sulfonic acid group in the form of sulfate ion, and it also decolorized bromine water. To a solution of 1 g of the reduced sodium salt there was added, with frequent shaking, a concentrated solution of 2 g of potassium permanganate. The solution became hot, and was quickly decolorized, the odor of benzaldehyde making its appearance. Toward the end of the reaction, the mixture was heated slightly on the water bath. The colorless filtrate, after the removal of the manganese dioxide, was concentrated to a small volume. After acidification, a white precipitate (m.p. 96°) came out of the solution. It had the characteristic odor of hydrocinnamic acid. As, in addition to the latter, the precipitate contained a considerable amount of benzoic acid, it was treated with an aqueous suspension of manganese oxide. The hydrocinnamic acid was distilled off with steam, and after neutralization with ammonia, precipitated with silver nitrate. A white precipitate formed, which after washing was recrystallized from hot water.

*Together with student G. A. Polonnikova.

3.796 mg substance: 1.609 mg Ag.
Found %: Ag 42.39.
 $C_9H_9O_2Ag$. Computed %: Ag 41.97.

SUMMARY

1. Upon heating with pyridine-sulfotrioxide, styrene is sulfonated to give a quantitative yield of ω -styrenesulfonic acid. The acid chloride, the amide, and the α -pyridylamide were also obtained.

2. Phenylbutadiene was sulfonated by means of the same reagent with a yield of ω -phenylbutadienesulfonic acid 50% of theory. The structure was shown by partial hydrogenation and oxidation of the product of hydrogenation to give phenylpropionic acid.

LITERATURE CITED

- [1] A.P.Terentyev, Bull. Moscow State Univ., 6, 28 (1947).
- [2] M.S.Kharasch, Priestley, J.Am.Chem.Soc., 61, 3425 (1939).
- [3] C.W.Jordan, J.Am.Chem.Soc., 63, 2687 (1941).
- [4] E.Simon, Ann., 31, 269 (1839).
- [5] P.Alekseev, J.Russ.Chem.Soc., 5, 400 (1873).
- [6] H.Erdmann, Ber., 17, 412 (1884); 24, 2771 (1891).
- [7] S.Gabriel, Ber., 18, 2436 (1885).
- [8] A. Quilico, E. Fleischner, Atti reale accad. Lincei, (6) 7, 141 (1928).
- [9] F.G.Bordwell, C.M.Suter, A.J.Webber, J.Am.Chem.Soc., 67, 827 (1945); 68, 139 (1946).
- [10] F.G.Bordwell, C.S.Randestvedt, J.Am.Chem.Soc., 70, 2429 (1948).
- [11] M.S.Kharasch, R.T.E.Schenk, F.R.Mayo, J.Am.Chem.Soc., 61, 3092 (1939).
- [12] F.Kohler, Am.Chem.J., 20, 680 (1898).
- [13] P. Friedlander, J. Mahly, Ber., 16, 848 (1883).
- [14] S.B.Lebedev and A.A.Ivanov, J.Russ.Chem.Soc., 48, 997 (1916).
- [15] A.P.Terentyev, M.E.Zegelman, Sci.Notes, Moscow State University, 6, Chemistry, 257 (1936).
- [16] O.Grumbitt, E.J.Becker, J.Am.Chem.Soc., 70, 149 (1948).
- [17] A.Klages, Ber., 37, 2309 (1902).

Received January 25, 1949.

γ-BROMOPROPYLACETOACETIC ESTER

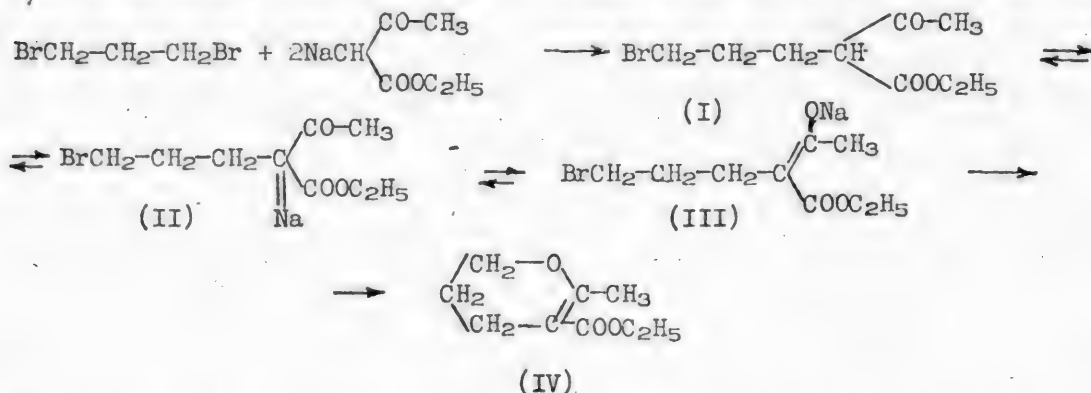
V. P. Golmov

Stavropol Medical Institute

In 1886, Lipp [2], by the action of sodio-acetoacetic ester (1 mole) on trimethylene bromide (1 mole) obtained in a yield 70% of theory a product which was in the form of a liquid that could not be distilled without decomposition at ordinary pressure. This undistillable product was subjected to analysis, and its content of bromine corresponded to that of γ-bromopropylacetoacetic ester, for which Lipp took it. The reactions of the substance which had been obtained apparently confirmed its identity with γ-bromopropylacetoacetic ester. Thus, for example, on boiling the substance with hydrochloric acid, CO₂ was evolved, and acetobutyl alcohol was formed. The latter, in Lipp's opinion, was obtained from the ω-bromobutylmethyl ketone first formed by the ketonic cleavage of γ-bromopropylacetoacetic ester.

Having need of γ-bromopropylacetoacetic ester in our work, and wishing to obtain it in pure form, we repeated Lipp's experiments, and subjected the reaction product to fractional distillation in vacuum. It appeared, during this, that under the conditions described by Lipp, γ-bromopropylacetoacetic ester was formed in only negligible quantity, while the chief portion of the reaction product was a mixture consisting of acetoacetic ester and trimethylene bromide which had not reacted, and of 2-methyl-5,6-dihydropyran-3-carboxylic ester, which had been obtained by Perkin, Jr. [3] by the interaction of 2 moles of sodio-acetoacetic ester with 1 mole of trimethylene bromide.

The formation of this substance must take place in the following manner:



The absence of γ-bromopropylacetoacetic ester from the products of reaction indicated that the formation of the product (IV) took place with very great velocity.

As the reaction of 1 mole of sodio-acetoacetic ester with 1 mole of trimethylene bromide could form, in accordance with the above equations, only 0.5 mole of the cyclic ester, the mixture obtained must consist of 0.5 mole of 2-methyl-5,6-

dihydropyran-3-carboxylic ester, 0.5 mole of acetoacetic ester, and 0.5 mole of trimethylene bromide. Such a mixture would contain 31.9% of bromine, which corresponds accurately to the bromine content of γ -bromopropylacetoacetic ester. In addition, as Perkin showed, the 2-methyl-5,6-dihydropyran-3-carboxylic ester which he obtained was converted, by the action of dilute acids, like the product obtained by Lipp, into acetobutyl alcohol.

On the basis of everything that has been said, it is completely obvious that Lipp did not have in his possession γ -bromopropylacetoacetic ester.

In order to obtain this substance, we altered the conditions of reaction, using a method of procedure which we had already utilized with success in the preparation of γ -bromopropylmalonic ester from sodiomalonic ester and trimethylene bromide [1]. This method required the use of a large excess of the malonic ester (in comparison with the metallic sodium), with the objective of preventing the conversion of the γ -bromopropylmalonic ester into cyclobutane-1,1-dicarboxylic ester, and also of an excess of trimethylene bromide, in order to avoid the formation of the ester of pentane-1,1,5,5-tetracarboxylic acid.

By carrying out the reaction of sodio-acetoacetic ester with trimethylene bromide in a similar manner, that is, by using 4 moles of acetoacetic ester and 4 moles of trimethylene bromide per 1 g-atom of metallic sodium, we actually obtained γ -bromopropylacetoacetic ester, with, however, a yield of only 11.5% of theory. A great part of the γ -bromopropylacetoacetic ester, even under these conditions, which were unfavorable to its cyclization, was none the less capable of being converted into 2-methyl-5,6-dihydropyran-3-carboxylic ester, which was obtained in the reaction in a yield 65% of theory. The results obtained by us indicate that the velocity of the formation of the six-membered dihydrogenated heterocycle is considerably greater than the velocity of formation of the cyclobutane ring, as under completely identical conditions, cyclobutane-1,1-dicarboxylic ester is hardly formed by the action of trimethylene bromide on sodiomalonic ester, while γ -bromopropylmalonic ester is formed in a yield 70% of theory, [1]

EXPERIMENTAL

The action of sodio-acetoacetic ester on trimethylene bromide (according to Lipp). 90 g (0.45 mole) of trimethylene bromide was placed in a flask, and with mechanical stirring, there was gradually added to it a solution of sodio-acetoacetic ester, prepared from 58 g (0.45 mole) of acetoacetic ester, 10.3 g (0.45 g-atom) of metallic sodium, and 150 ml of absolute alcohol. After the addition of all of the solution of sodio-acetoacetic ester, the stirring was continued for another half hour, and the mixture was then heated on a bath for an hour. Water was added to the reaction mixture, and the oil which separated out was extracted with ether. The ether extract was washed twice with water, and dried with fused calcium chloride. After the ether had been driven off, there remained 91 g of product which was then fractionated in vacuum with the use of a Vigreux column 20 cm high. Upon distillation, the following fractions were obtained:

I	53-59° at 10 mm,	45.0 g,
II	60-95° at 8 mm,	11.5 g,
III	96-97° at 8 mm,	26.8 g,
IV	95-135° 4 mm,	1.7 g,
V	Residue (tarred)	4.6 g.

Fraction I was a mixture of trimethylene bromide and acetoacetic ester. Fraction III, upon repeated distillation, boiled within the limits 104-105° at 11 mm.

d_4^{20} 1.0759; n_D^{20} 1.4780; M_R 44.73. $C_9H_{14}O_3$. Computed: M_R 44.39.

0.1534 g substance: 0.3560 g CO₂; 0.1154 g H₂O.
Found %: C 63.29; H 8.35.
C₉H₁₄O₃. Computed %: C 63.53; H 8.23.

The substance was an ester, which was saponified with an aqueous solution of caustic potash; upon acidification of the alkaline solution, a solid acid precipitated out, soluble with difficulty in water. After recrystallization from alcohol, this melted at 116-117°. Thus, fraction III consisted of the ester of 2-methyl-5,6-dihydropyran-3-carboxylic acid, obtained by Perkin [3] by the action of sodio-acetoacetic ester on trimethylene bromide.

Fraction IV, which boiled, as indicated above, over a very broad range, was colored yellow, and gave a reaction for halogen by the Beilstein test. It is very probable that it contained γ -bromopropylacetoacetic ester, but it was impossible to obtain this in pure form because of the extremely small amount of the substance present.

The preparation of γ -bromopropylacetoacetic ester. To a flask fitted with a mechanical stirrer, a reflux condenser, and a dropping funnel which was in its turn joined to a reflux condenser, there was added a mixture of 162 g (0.8 mole) of trimethylene bromide and 104 g (0.8 mole) of acetoacetic ester. Alcoholate was prepared in the dropping funnel from 4.7 g (0.2 g-atom) of sodium and 75 ml of absolute alcohol. The alcoholate solution was slowly added, with mechanical stirring, to the reaction mixture. After the spontaneous reaction was complete, the flask was heated for 2 hours on the water bath. Then water was added to the contents of the flask, the reaction products were extracted with ether, and the ether extract was washed twice with water, dried with fused calcium chloride, the ether driven off, and the residue fractionated in vacuum with a Vigret column 20 cm high. This gave (as the average of 5 experiments):

Fraction I - up to 100° at 166 mm, 210 g.

Fraction II - residue from distillation 22 g.

The experiment was carried out 5 times, Fraction I being utilized for further work. It was a mixture of trimethylene bromide with acetoacetic ester to which there had been added an insufficient amount of the original substances. As it was difficult to separate this mixture by distillation, the amounts of its components were determined from the index of refraction. As a result of 5 experiments, a total of 110 g of residue was obtained from the first distillation, which was further fractionated as a whole. After two distillations, the following fractions were obtained.

I up to 115° at 20 mm, 4.8 g,
II 111-112° at 15 mm, 55.3 g,
III 113-153° at 15 mm, 5.8 g,
IV 154-157° at 15 mm, 28.8 g,
V Residue (dark and viscous), 10.1 g.

The 111-112° fraction was 2-methyl-5,6-dihydropyran-3-carboxylic ester (yield 65% of theory).

The 154-157° fraction, upon a second distillation, had b.p. 144-145° at 10 mm, and was an oily, slightly yellowish liquid. The substance gave a positive reaction for halogen by the Beilstein test.

d_4^{20} 1.2844; n_D^{20} 1.4700; MR_D 54.52.

C₉H₁₅O₃Br. Computed (for the keto form): MR_D 53.19.

Computed (for the enol form): MR_D 54.38.

0.1338 g substance: 5.25 ml 0.1 N AgNO₃.

Found %: Br 31.39.

C₉H₁₅O₃Br. Computed %: Br 31.87.

Thus, this fraction was γ -bromopropylacetoacetic ester (yield 11.5% of theory).

3-Methyl-1-phenyl-4-(γ -bromopropyl)-pyrazolone-5. 2.5 g of γ -bromopropylacetoacetic ester was mixed in a test tube with 1.5 g of phenylhydrazine. The mixture developed heat, and became cloudy because of the separation of water. Upon being heated briefly up to 100°, the contents of the test tube were converted into a crystalline mass. The crystals were filtered with suction from the mother liquid, and after two recrystallizations from alcohol, melted with decomposition, unclearly, at about 190°.

0.0980 g substance: 6.55 ml 0.1 N H_2SO_4 (Kjeldahl)

Found %: N 9.37.

$\text{C}_{13}\text{H}_{15}\text{ON}_2\text{Br}$. Computed %: N 9.49.

SUMMARY

1) The reaction of equivalent amounts of sodioacetoacetic ester and trimethylene bromide, contrary to the report of Lipp, forms only traces of γ -bromopropylacetoacetic ester, the chief product of reaction being 2-methyl-5,6-dihydropyran-3-carboxylic ester, which was obtained by Perkin, Jr. by the action of two moles of sodio-acetoacetic ester on 1 mole of trimethylene bromide.

2. γ -Bromopropylacetoacetic ester was obtained in yield 11.5% of theory by the action of sodio-acetoacetic ester on trimethylene bromide, when 4 moles of acetoacetic ester and 4 moles of trimethylene bromide were used per 1 g-atom of metallic sodium.

3. From a comparison of these results with the results obtained by the action of sodio-malonic ester on trimethylene bromide under the same conditions, we may conclude that the velocity of formation of the six-membered dihydropyran heterocycle is considerably greater than the velocity of formation of the cyclobutane ring. This, probably, also determines the unusual course of the reaction investigated by us, as a result of which the dihydropyran derivative is obtained instead of the 1-acetylcyclobutane-1-carboxylic ester.

LITERATURE CITED

[1] V.P. Golmov, J. Gen. Chem. 19, 1679 (1949).

[2] Lipp, Ber., 18, 3279 (1885).

[3] Perkin, Jr., Ber., 19, 2557 (1886).

Received November 22, 1948.

See CB translation p. a-109 ff-

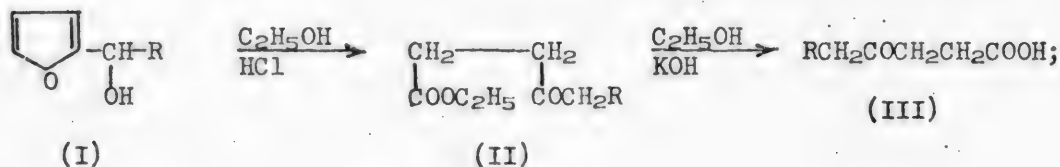
THE ISOMERIC TRANSFORMATIONS OF CARBINOLS OF THE FURAN SERIES

IV. THE SYNTHESIS OF ALIPHATIC AND ALIPHATIC-AROMATIC γ -KETOACIDS

V. F. Kucherov

In one of our preceding communications [1], we have described a method for the synthesis of various aliphatic γ -ketoacids by means of a complicated allyl rearrangement of alkylfuryl carbinols. This permits the ready preparation of these compounds. In the present communication, this method is applied to the synthesis of more complicated aliphatic and aliphatic-aromatic γ -ketoacids, which are not very accessible by other methods.

We have shown that *n*-butylfuryl carbinol (I, a), isobutylfuryl carbinol (I, b), and β -phenylethylfuryl carbinol (I, c), under the action of an alcoholic solution of hydrogen chloride and heat, are converted, in yields up to 50%, into the esters of the corresponding ketoacids (II, a; II, b; II, c), which upon saponification with alcoholic alkali readily give the corresponding γ -ketoacids (III, a; III, b; III, c).



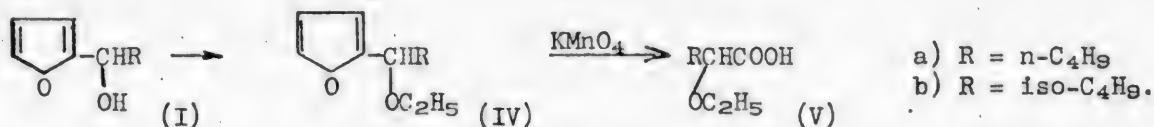
- a) R = *n*-C₄H₉
- b) R = *iso*-C₄H₉
- c) R = C₆H₅CH₂CH₂.

In contrast to what happens with the simpler alkyl furyl carbinols, in this case the allyl rearrangement is accompanied by the formation of several byproducts of the reaction, because of which the isolation of the main products formed in the reaction, the esters of the γ -ketoacids, requires repeated fractionation in vacuum. Under the conditions of the reactions, as listed in the experimental section, we were able to isolate, in addition to the esters of the γ -ketoacids, small amounts of the original alkylfuryl carbinols and their ethyl ethers. In addition, repeated distillation of the intermediate fractions made it possible to obtain small amounts of a few additional products of the transformation of alkylfuryl carbinols, with unknown structures.

Despite the complicated nature of the reactions involved in the transformation of alkylfuryl carbinols under the influence of hydrogen chloride, these reactions are completely applicable as a method of synthesis of the aliphatic and aliphatic-aromatic γ -ketoacids. The alkylfuryl carbinols needed for this may be obtained in good yield from furfural by the Grignard reaction, as has been described in a preceding communication [1].

Like the simpler alkylfuryl carbinols, the carbinols of the furan series

investigated by us, under the action of small amounts of hydrogen chloride in alcoholic solution, at room temperature, easily give the ethyl ethers (IV, a; IV, b).



The structures of these ethyl ethers of n-butyl and isobutyl furyl carbinols were demonstrated by the oxidation of their neutral solutions with permanganate. This led to the formation of α -ethoxy-n-caproic acid (V, a) and α -ethoxy-isocaproic acid (V, b). The first of these acids has been described in the literature [2].

Analyses of the compounds obtained was carried out in our laboratory by Z.V. Volodina.

EXPERIMENTAL

1. The Preparation of Various Alkylfuryl Carbinols

a) n-Butylfuryl carbinol (I, a). To a Grignard reagent prepared from 60 g of Mg and 300 g of n-butyl bromide in 800 ml of absolute ether, there was added, drop by drop, with vigorous stirring, and cooling of the solution, 170 g of freshly distilled furfural in 200 ml of absolute ether. The velocity of the addition of the furfural and the cooling were so regulated that the reaction temperature of the mass did not exceed +10°. After this, the product of reaction was boiled for 4 to 5 hours with vigorous stirring, cooled, and slowly poured upon a large amount of ice. The ether layer was removed by decantation, and the residue was decomposed by the addition of 15% acetic acid. The ether layer was removed, and the united ether solutions was washed 2 or 3 times with water, twice with a 10% solution of potash, then carefully with a 10% solution of sodiumbisulfite, and dried over anhydrous Na₂SO₄. After the ether had been driven off, the residue was distilled in vacuum with a dephlegmator, the fraction with boiling range 75-86° at 3 mm being collected. After another distillation with a $\frac{1}{2}$ meter dephlegmator, there was obtained 210 g (77%, computed on the basis of the furfural) of an individual substance with b.p. 78-80° at 3 mm; n_D^{15} 1.4765; d_4^{15} 1.0011.

0.1487 g substance: 0.3801 g CO₂; 0.1174 g H₂O.

0.1263 g substance: 0.3234 g CO₂; 0.1001 g H₂O.

Found %: C 69.87, 69.92; H 8.77, 8.82.

C₉H₁₄O₂. Computed %: C 70.09; H 9.15.

b) Isobutylfuryl carbinol (I, b). This was obtained as above from 300 g of isobutyl bromide, 60 g of Mg, and 170 g of furfural, after 2 distillations in vacuum with a $\frac{1}{2}$ meter dephlegmator. 210 g (77%) of the pure carbinol was obtained, with b.p. 81-82° at 5 mm; n_D^{15} 1.4690; d_4^{15} 0.9946.

0.1256 g substance: 0.3225 g CO₂; 0.1036 g H₂O.

Found %: C 70.03; H 9.16.

C₉H₁₄O₂. Computed %: C 70.09; H 9.15.

c) β -Phenylethylfuryl carbinol [3] (I, c). This was obtained as above, in 82% yield, from 100 g of β -phenylethyl bromide, 13.2 g of Mg, and 40 g of furfural. After distillation in vacuum with a dephlegmator, the carbinol had b.p. 168-170° at 11 mm, which corresponded to the data in the literature.

2. The preparation of the Ethyl Esters of γ -Ketoacids

a) The ethyl ester of 4-ketononanoic acid (II, a). To a solution of 280 g of n-butylfuryl carbinol in 1000 ml of absolute alcohol there was added 10 ml of an alcoholic solution of hydrogen chloride (0.28 g HCl in 1 ml). The solution

was boiled on the water bath for 3 hours. Two thirds of the alcohol was driven off, and the rest was poured into a saturated solution of potash, carefully extracted with ether, and the ether layer dried over anhydrous potash. After the ether had been driven off, the residue was distilled in vacuum with a dephlegmator 20 cm long. The fraction that was collected had a boiling range from 75 to 100° at 3 mm, and weighed 200 g.

After two distillations in vacuum with a $\frac{1}{2}$ meter dephlegmator, 162 g of the pure ethyl ester of 4-ketononanoic acid was obtained, with b.p. 96-98° at 4 mm. Yield 44.5%: n_D^{15} 1.4365; d_4^{15} 0.9578.

0.1372 g substance: 0.3317 g CO₂; 0.1204 g H₂O.

Found %: C 65.93; H 9.76.

C₁₁H₂₀O₃. Computed %: C 65.95; H 10.06.

b) The ethyl ester of 7-methyl-4-ketooctanoic acid (II, b). This was prepared like the preceding ester from 180 g of isobutylfuryl carbinol. The main fraction (160 g) had a boiling range of 75-95° at 4 mm. After two distillations in vacuum with a $\frac{1}{2}$ meter dephlegmator, 120 g of the pure ethyl ester of 7-methyl-4-ketooctanoic acid was obtained, with b.p. 91-92° at 3 mm. Yield 51.3%: n_D^{15} 1.4310; d_4^{15} 0.9560.

0.1088 g substance: 0.2642 g CO₂; 0.0975 g H₂O.

Found %: C 66.22; H 9.94.

C₁₁H₂₀O₃. Computed %: C 65.96; H 10.06.

c) The ethyl ester of 7-phenyl-4-ketoheptanoic acid (II, c). This was obtained like the preceding ester, from 60 g of β -phenylethylfuryl carbinol. The main fraction, of 45.5 g, boiled from 170 to 175° at 5 mm. After repeated distillation in vacuum with a $\frac{1}{2}$ meter dephlegmator, 35.5 g (48.5%) of the pure ester of 7-phenyl-4-ketoheptanoic acid was obtained, with b.p. 166-168° at 3 mm: n_D^{15} 1.4975; d_4^{15} 1.0495.

0.1210 g substance: 0.3234 g CO₂; 0.0884 g H₂O.

Found %: C 72.71; H 8.12.

C₁₅H₂₀O₃. Computed %: C 72.55; H 8.12.

3. The Preparation of the γ -Ketoacids

a) 4-Ketononanoic acid (III, a). To a solution of 8.5 g of KOH in 85 ml of methanol, 15 g of the ethyl ester of 4-ketononanoic acid was added, and the solution was boiled for 1 hour on the water bath. The methanol was driven off until one third the original volume remained, and the residue was poured into water. The solution was filtered with carbon, and then cooled and acidified with concentrated HCl until there was an acid reaction to Congo red. The light yellow precipitate was filtered off, washed with water, and dried. The weight was 11.2 g (95%), the m.p. 68-70°. After crystallization from petroleum ether, the substance was in the form of colorless, shining platelets, with m.p. 70-71°. For analysis, the substance was dried in a vacuum dessicator over sulfuric acid.

0.1222 g substance: 0.2821 g CO₂; 0.1037 g H₂O.

0.1226 g substance: 0.2823 g CO₂; 0.1016 g H₂O.

Found %: C 62.96, 62.80; H 9.43, 9.20.

C₉H₁₆O₃. Computed %: C 62.76; H 9.37.

b) 7-Methyl-4-ketooctanoic acid (II, b). In the same way as the preceding acid, this was obtained in 90% yield by saponification of the ethyl ester. It was in the form of shining platelets (from petroleum ether) with m.p. 51-52°.

0.1197 g substance: 0.2767 g CO₂; 0.1020 g H₂O.

Found %: C 63.03; H 9.47.

C₉H₁₆O₃. Computed %: C 62.76; H 9.37.

c) 7-Phenyl-4-ketooheptanoic acid (III, c). This was obtained in the same way as the preceding acid. Recrystallization from petroleum ether gave colorless shining platelets with m.p. 77-78°. Yield 77%.

0.1170 g substance: 0.2810 g CO₂; 0.0785 g H₂O.

Found %: C 71.06; H 7.50.

C₁₃H₁₆O₃. Computed %: C 70.89; H 7.32.

4. The Preparation of the Ethyl Ethers of Several Alkylfuryl Carbinols.

a) The ethyl ether of n-butylfuryl carbinol (IV, a). To a solution of 45 g of n-butylfuryl carbinol in 200 ml of absolute alcohol there was added 1.2 ml of an alcoholic solution of hydrogen chloride (0.28 g HCl in 1 ml). The mixture was allowed to stand at room temperature for 5 days. The solution was then poured into a large volume of cold water, carefully extracted with ether, and the ether extract washed with a 10% solution of potash, and dried over anhydrous Na₂SO₄. The ether was driven off, and the residue was distilled in vacuum with a $\frac{1}{2}$ meter dephlegmator.

There was obtained 47.5 g (90%) of an individual product with b.p. 79-81° at 7 mm; n_D¹⁵ 1.4520; d₄¹⁵ 0.9272.

0.1545 g substance: 0.4097 g CO₂; 0.1349 g H₂O.

0.1748 g substance: 0.4624 g CO₂; 0.1532 g H₂O.

Found %: C 72.32, 72.14; H 9.70, 9.74.

C₁₁H₁₈O₂. Computed %: C 72.48; H 9.95.

b) The ethyl ether of isobutylfuryl carbinol (IV, b). This was obtained like the preceding ether, from 40 g of isobutylfuryl carbinol. There was obtained 41 g (89%) of the ethyl ether with b.p. 75-77° at 7 mm; n_D¹⁵ 1.4465; d₄¹⁵ 0.9225.

0.1074 g substance: 0.2844 g CO₂; 0.0946 g H₂O.

Found %: C 72.37; H 9.74.

C₁₁H₁₈O₂. Computed %: C 72.48; H 9.95.

5. The Oxidation of the Ethyl Ethers of Alkylfuryl Carbinols

a) α -Ethoxy-n-caproic acid. To a solution of 23 g of the ethyl ether of n-butylfuryl carbinol in 380 ml of pure acetone there was slowly added, at a temperature from 5 to 10°, a solution of KMnO₄ in 2.3 liters of water. In order to start the oxidation, 2 to 3 ml of a 10% KOH solution was added.

At the end of the oxidation, the MnO₂ precipitate was filtered off and carefully washed with hot water. The united aqueous solutions were evaporated in vacuum at a temperature of 50 to 60° almost to dryness. The residue was treated, with cooling, with 30% sulfuric acid. The oil which separated out was extracted with ether, and the ether extract was washed with a small amount of water and dried over anhydrous Na₂SO₄. After the ether had been driven off, the residue was distilled in vacuum with a $\frac{1}{2}$ meter dephlegmator, the fraction which boiled from 82 to 90° at 2 mm being collected. After another distillation 5.8 g (30% of the theoretical amount) of α -ethoxy-n-caproic acid was obtained with b.p. 125-127° at 11 mm. The acid was distilled without decomposition at atmospheric pressure, and had b.p. 232-235° at 755 mm; n_D¹⁵ 1.4262; d₄¹⁵ 0.9690.

According to the data in the literature [2] α -ethoxy-n-caproic acid has b.p. 124.5° at 10 mm.

Determination of the equivalent of the acid:

0.3148 g substance: 19.0 ml 0.1 N NaOH.

Found: equiv. 165.7.

C₇H₁₅O(COOH). Computed: equiv. 160.2.

b) α -Ethoxyisocaproic acid. In the same manner as the preceding acid, from 15 g of the ethyl ether of isobutylfuryl carbinol, there was obtained, after two distillations, 4.2 g (32%) of α -ethoxyisocaproic acid with b.p. 84-86° at 3 mm. The acid distilled without decomposition at atmospheric pressure, and had b.p. 222-224° at 752 mm: n_D^{17} 1.4270; d_4^{15} 0.9665.

0.1234 g substance: 0.2712 g CO₂; 0.1122 g H₂O.

Found %: C 59.89; H 10.09.

C₈H₁₆O₃. Computed %: C 59.97; H 10.07.

Determination of the equivalent of the acid:

0.2300 g substance: 13.75 ml 0.1 N NaOH.

Found: equiv. 166.1.

C₇H₁₅O(COOH). Computed: equiv. 160.2.

SUMMARY

1. A method for the synthesis of the simpler γ -ketoacids by means of the allyl rearrangement of alkylfuryl carbinols has been extended to the preparation of several new aliphatic and aliphatic-aromatic γ -ketoacids.

2. It has been shown that under gentle conditions, the action of hydrogen chloride on n-butyl and isobutylfuryl carbinols in alcoholic solution takes place with good yields of the ethyl ethers of these carbinols, and that the latter, upon oxidation, give 30% yields of α -ethoxy-n-caproic acid and α -ethoxyisocaproic acid.

LITERATURE CITED

- [1] M.I.Ushakov, V.F.Kucherov, J.Gen.Chem. 14, 1080 (1944).
- [2] Blaise, Picard, Comptes rend., 152, 446.
- [3] R.Paul, Comptes rend., 202, 854 (1936).

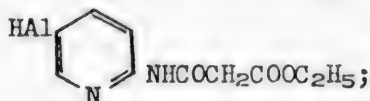
Received December 21, 1948.

INVESTIGATIONS IN THE DOMAIN OF AMINO DERIVATIVES OF THE HETEROCYCLIC SERIES

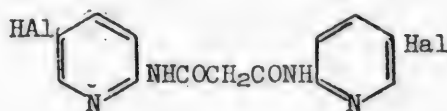
V. THE CONDENSATION PRODUCTS OF 5-HALOGEN-2-AMINOPYRIDINES WITH ACETOACETIC ESTER

V. F. Kucherov

As has been described in one of our communications [1], the condensation of 5-halogen-2-aminopyridines with malonic ester leads, in contrast to the case of α -aminopyridine itself, to the formation of a mixture of two non-cyclic products of reaction, with structures (I) and (II):



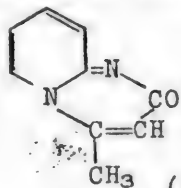
(I)



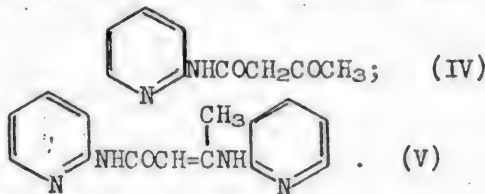
(II)

This character of the condensation, which is the result chiefly of the decreased tendency of the substituted α -aminopyridines to tautomerize, is of interest for the study of their condensations with acetoacetic ester, all the more so as a similar reaction, investigated with α -aminopyridine itself, takes place in a rather complicated and interesting manner.

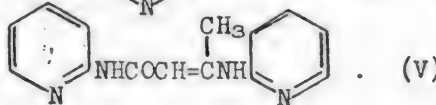
As has been established by the work of S. Khitnik [2], the chief condensation product of α -aminopyridine with acetoacetic ester is a cyclic product of the composition $C_9H_8ON_2$ (III), whose formation is accompanied by the simultaneous synthesis of two intermediate non-cyclic products of reaction (IV) and (V).



(III)



(IV)



(V)

The formation of a bicyclic reaction product takes place also in the condensation of α -aminonicotine with acetoacetic ester [3].

We have investigated all this in detail in the condensation of 5-halogen-2-aminopyridines with acetoacetic ester.

It was discovered that when 5-halogen-2-aminopyridines were heated with a 2 to 3-fold excess of acetoacetic ester, the condensation began even at 140-150°, and was accompanied by the distillation of an alcohol-containing liquid. It was

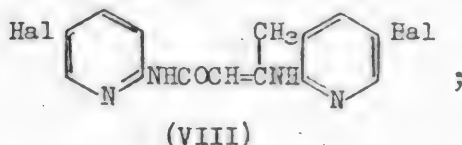
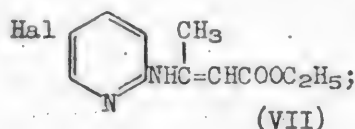
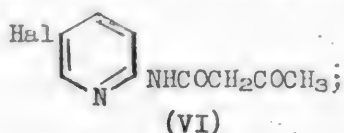
practically complete after 40 to 50 minutes of heating at 160-170°. By treatment of the solid reaction product obtained after cooling with different solvents and by fractional crystallization (cf. experimental section) we were able to isolate three individual substances, sharply distinguished from each other by melting points, solubility, and elementary composition.

One of these condensation products, consisting of 60-65% by weight of the original 5-halogen-2-aminopyridine, had an elementary composition of $C_9H_8O_2N_2Hal$ (VI) and was thus a product of the splitting off of a molecule of alcohol from one molecule of 5-halogen-2-aminopyridine and one molecule of acetoacetic ester.

The second condensation product was high melting, and soluble with difficulty in the usual organic solvents. It amounted to 5-10% by weight of the original 5-halogen-2-aminopyridine, and had the composition $C_{11}H_{13}O_2N_2Hal_2$ (VIII). This corresponded to the product of the cleavage of one molecule of water and one molecule of alcohol from two molecules of 5-halogen-2-aminopyridine and one molecule of acetoacetic ester.

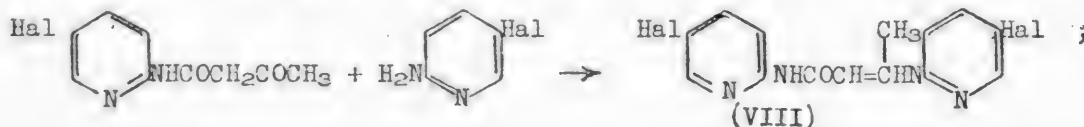
The third reaction product, obtained in very small amount, had a low melting point and was very soluble in organic solvents (this made its isolation extremely difficult). It had an elementary composition of $C_{11}H_{13}O_2N_2Hal$ (VII), and corresponded to a product of the cleavage of one molecule of water from one molecule of 5-halogen-2-aminopyridine and one molecule of acetoacetic ester.

Corresponding to the elementary composition and the previously noted fact of the difficulty of tautomeric transformation with substituted α -aminopyridines, we can ascribe the following structures to these condensation products:



- a) Hal = Cl;
b) Hal = Br;
c) Hal = I.

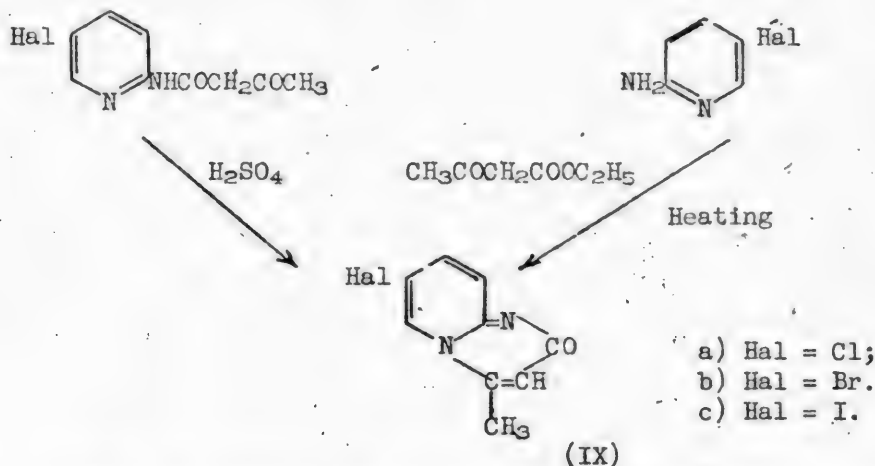
The structures of compounds (VI), as 5-halogen-2-acetoacetyl aminopyridines, and of compounds (VIII) as 5'-halogendipyridyl amides of β -(5-halogenpyridyl-2)-aminocrotonic acid, does not arouse any doubt, as these compounds correspond completely in their properties to the data existing in the literature [2]. In addition, the compounds (VIII) can easily be obtained by heating 5-halogen-2-acetoacetyl aminopyridines with an equimolecular amount of the corresponding 5-halogen-2-aminopyridine. This reaction, which is a confirmation of the structure of the compounds (VIII), may be represented by the following equation.



- a) Hal = Cl; b) Hal = Br; c) Hal = I.

The third condensation product (VII), which according to the analysis has the structure of β -(5-halogenpyridyl-2)-aminocrotonic ester, is characteristic of the condensation products of many amines with acetoacetic ester [4]. It was not isolated from the reaction with α -aminopyridine, and therefore its structure requires additional confirmation.

The condensation of 5-halogen-2-aminopyridines with acetoacetic ester is not limited to the formation of only the three non-cyclic condensation products described above. It was found that if a mixture of equivalent amounts of 5-halogen-2-aminopyridines and acetoacetic ester is heated under more severe conditions (30 minutes at 190-195°), then after treatment of the reaction product, it is possible to isolate in 20-25% yield a new condensation product, which differs in its properties from the three previously obtained, and has, according to its analysis, a composition which corresponds to the cyclic condensation product $C_9H_7ON_2Hal$ (IX). This same product can be obtained in from 60 to 75% yield by heating the corresponding 5-halogen-2-acetoacetylaminopyridines (VI) with concentrated sulfuric acid. In accordance with the data of S. Khitrik [2] for α -aminopyridine, this product should have the structure 1,2-(3'-halogendivinylene)-6-methylpyrimidone-4. The equations for the transformations may be expressed in the following manner:



Thus, using as an example the condensation of 5-halogen-2-aminopyridines with acetoacetic ester, depending on the conditions of condensation, it is possible to observe the formation of four reaction products, one of which has the possible cyclic structure of a 3'-halogen substituted 1,2-divinylene-6-methylpyrimidone-3.

The experimental part of the present work was carried out with the participation of Z.V.Volodina. The analyses were carried out in our laboratory by F.V. Rasina.

EXPERIMENTAL

I. The Condensation of 5-Halogen-2-aminopyridines with Acetoacetic Ester

1. The condensation of 5-iodo-2-aminopyridine. A mixture of 20 g (0.09 mole) of 5-iodo-2-aminopyridine and 29 g (0.225 mole) of freshly distilled acetoacetic ester was heated slowly in a Claisen flask on the oil bath. The reaction began at 140-150°, and was accompanied by the distillation of a liquid which contained alcohol. The reaction mixture was heated for 40 to 45 minutes at a temperature inside the flask of 160-170°. During this time, 6 ml of liquid distilled off. The reaction product, which hardened on cooling, was treated with 60 ml of cold methanol, and the precipitate was filtered off, washed with cold methanol, and dried. There was obtained 15.5 g of a crystalline reaction product, which melted in the interval 165-172°. The product was treated with a large quantity of hot methanol, and the insoluble amorphous precipitate was filtered off. The weight was 1.1 g, the m.p. 223-225°. After recrystallization from a large volume of benzene, 0.95 g of material was obtained in the form of fine,

colorless needles with m.p. 227-229°. For analysis the substance was dried in a vacuum at 100° for 4 hours.

0.1144 g substance: 11.15 ml N₂ (21.5°, 743 mm).

0.1031 g substance: 10.2 ml N₂ (24°, 747 mm).

0.1244 g substance: 0.1148 g AgI.

Found %: N 10.95, 10.85; I 49.88.

C₁₄H₁₂ON₄I₂. Computed %: N 11.07; I 50.15.

Thus, from its analysis, this substance had the composition of the 5'-iodopyridylamide of β-(5-iodopyridyl-2)-aminocrotonic acid (VIII, c).

The methanol mother liquid obtained after the separation of (VIII, c) was evaporated until crystallization began. The crystalline product which separated out on cooling was filtered off and washed with cold methanol. There was obtained 12.3 g of a substance with m.p. 171-173°. After another crystallization, the substance had m.p. 172-173°, and was obtained in the form of large, colorless needles. For analysis, the substance was dried in vacuum at 100° for 5 hours.

0.1150 g substance: 8.95 ml N₂ (20.5°, 764.5 mm).

0.1354 g substance: 0.1040 g AgI.

Found %: N 9.02; I 41.52.

C₈H₈O₂N₂I. Computed %: N 9.22; I 41.73.

From its analysis, the given substance had the composition of 5-iodo-2-acetoacetyl aminopyridine (VI, c).

The methanol mother liquor, obtained from the first treatment of the condensation product with cold methanol, and containing an excess of acetoacetic ester, was evaporated to dryness in vacuum, and the crystalline residue was extracted repeatedly with small amounts of petroleum ether. The extract was evaporated to half its volume, the precipitate which formed was filtered off (it was the impure original 5-iodo-2-aminopyridine), and the filtrate was evaporated to dryness in the air. The residue was a light yellow substance which crystallized in the form of fine long needles and had m.p. 68-75°. It was recrystallized twice from a small amount of methanol with carbon. 0.9 g of an individual crystalline substance was obtained in the form of long colorless needles with m.p. 83-84°. After drying in a vacuum desiccator over sulfuric acid, the substance, from its analysis, had the composition of β-(5-iodopyridyl-2)-aminocrotonic ester (VII, c).

0.1048 g substance: 8.0 ml N₂ (24°, 748 mm).

0.1240 g substance: 9.15 ml N₂ (19°, 747.5 mm).

0.1520 g substance: 0.1076 g AgI.

Found %: N 8.38, 8.42; I 38.27.

C₁₁H₁₃O₂N₂I. Computed %: N 8.43; I 38.21.

2. The condensation of 5-bromo-2-aminopyridine. A mixture of 20 g (9.115 mole) of 5-bromo-2-aminopyridine and 30 g (0.23 mole) of acetoacetic ester was heated on an oil bath at a temperature of 160-170° (inside the reaction mixture) for 40 minutes. 4.5 ml of liquid was driven off; its boiling point was 75-80°.

The reaction product, which hardened upon cooling, was treated as in the preceding experiment and the following substances were obtained.

a) A high-melting substance (1.8 g) insoluble in hot methanol. After recrystallization from a large volume of chloroform, it was obtained in the form of fine needle-shaped crystals with a constant m.p. of 240-241°. After drying in a vacuum at 100° for 5 hours, the substance had, according to its analysis, a composition corresponding to the 5'-bromopyridyl amide of β-(5-bromopyridyl-2)-aminocrotonic acid (VIII, b).

0.1102 g substance: 13.8 ml N₂ (25°, 745 mm).
0.1236 g substance: 14.55 ml N₂ (18°, 754 mm).
0.1748 g substance: 0.1586 g AgBr.

Found %: N 13.62, 13.61; Br 38.61.
C₁₄H₁₂ON₄Br₂. Computed %: N 13.59; Br 38.78.

b) From the chief methanol mother liquid, after removal of substance (VIII, b), 11.2 g of a substance with m.p. 160-163° was isolated. After crystallization from methanol, this substance was obtained in the form of large, colorless needles with m.p. 164-165°. For analysis, it was dried in vacuum at 80° for 4 hours, and had a composition which corresponded to 5-bromo-2-acetoacetyl aminopyridine (VI, b).

0.1170 g substance: 11.15 ml N₂ (19°, 763.5 mm).
0.1370 g substance: 0.1004 g AgBr.

Found %: N 11.11; Br 31.18.
C₉H₉O₂N₂Br. Computed %: N 10.89; Br 31.08.

c) A low melting substance, isolated from the first mother liquid after driving off the acetoacetic ester in vacuum and treating with petroleum ether (in order to separate it from the original 5-bromo-2-aminopyridine). It was obtained in the form of long, fine, pale yellow needles with m.p. 88-92°. After two crystallizations from a small amount of methanol, the substance obtained (0.9 g) had m.p. 89-90°, and from its analysis had the composition of a β-(5-bromopyridyl-2)-aminocrotonic ester (VII, b).

0.1058 g substance: 9.5 ml N₂ (22°, 740 mm).
0.1176 g substance: 10.15 ml N₂ (20°, 745 mm).
0.1260 g substance: 0.0832 g AgBr.

Found %: N 9.85, 9.76; Br 27.97.
C₁₁H₁₃O₂N₂Br. Computed %: N 9.83; Br 28.02.

3. The condensation of 5-chloro-2-aminopyridine. A mixture of 12.8 g (0.1 mole) of 5-chloro-2-aminopyridine and 26 g (0.2 mole) of acetoacetic ester was heated on the oil bath at a temperature of 160-170° (inside the flask) for 40 minutes. After the treatment which is described in detail for the condensation of 5-iodo-2-aminopyridine, the following were obtained:

a) A substance insoluble in hot methanol (2.1 g). After crystallization from a large amount of chloroform, it had m.p. 245-246° (fine needles). After drying in vacuum at 100° for 4 hours, the substance corresponded in analysis to the 5'-chloropyridylamide of β-(5-chloropyridyl-2)-aminocrotonic acid (VIII, a).

0.1160 g substance: 17.25 ml N₂ (20.5°, 758.5 mm).
0.1208 g substance: 0.1074 g AgCl.

Found %: N 17.12; Cl 21.99.
C₁₄H₁₂ON₄Cl₂. Computed %: N 17.34; Cl 21.94.

b) A substance whose analysis corresponded to the composition of 5-chloro-2-acetoacetyl aminopyridine (VI, a). It was obtained from the methanol solution after removal of substance (VIII, a). Weight 6.4 g. After crystallization from methanol, it had a constant m.p. of 155-156° (large colorless needles).

0.1274 g substance: 14.75 ml N₂ (17°, 749.5 mm).
0.1502 g substance: 0.1008 g AgCl.

Found %: N 13.34; Cl 16.60.
C₉H₉O₂N₂Cl. Computed %: N 13.13; Cl 16.67.

c) From the first mother liquor, after the removal of the acetoacetic ester and treatment with petroleum ether, there was obtained 2.1 g of a substance which after crystallization from a small amount of methanol had m.p. 84-85°. This substance corresponded according to its analysis to a β-(5-chloropyridyl-2)-aminocrotonic ester (VII, a).

0.1240 g substance: 12.5 ml N₂ (17°, 754.5 mm).

0.1350 g substance: 0.0780 g AgCl.

Found %: N 11.69; Cl 14.39.

C₁₁H₁₃O₂N₂Cl. Computed %: N 11.64; Cl 14.73.

II. The Synthesis of the 5'-Halogenpyridyl Amides of β -(5-Halogen-pyridyl-2)-aminocrotonic Acid

1. The 5'-iodopyridylamide of β -(5-iodopyridyl-2)-aminocrotonic acid (VIII, c). A mixture of 3 g (0.009 mole) of 5-iodo-2-acetoacetylaminopyridine, with m.p. 172-173°, and 2 g (0.009 mole) of 5-iodo-2-aminopyridine was heated on an oil bath in vacuum (20-30 mm) at 150-160° for 1 hour. The reaction product was treated with 150 ml of hot methanol and the insoluble residue was filtered off. There was obtained 2.1 g of a substance with m.p. 210-220°. After recrystallization from a large volume of hot benzene, 1.8 g of a substance was obtained with m.p. 226-228° (fine colorless needles). This gave no depression of the melting point with the 5'-iodopyridylamide of β -(5-iodopyridyl-2)-aminocrotonic acid, obtained by the direct condensation of 5-iodo-2-aminopyridine with acetoacetic ester.

From the methanol mother liquid there could be obtained, after driving off the methanol and recrystallizing the residue from methanol with carbon, 0.8 g of the original 5-iodo-2-acetoacetyl aminopyridine. The yield of 5'-iodopyridylamide of β -(5-iodopyridyl-2)-aminocrotonic acid amounted to 50%, basing the computation on the amount of 5-iodo-2-acetoacetyl aminopyridine that had reacted.

2. The 5'-Bromopyridylamide of β -(5-bromopyridyl-2)-aminocrotonic acid (VIII, b) was obtained in 55% yield by heating a mixture of equimolecular quantities of 5-bromo-2-acetoacetyl aminopyridine and 5-bromo-2-aminopyridine in a vacuum at 155-160° for 1 hour. The substance obtained, after crystallization from hot chloroform, had m.p. 240-242°, and did not give a depression of the melting point with a similar substance isolated from the direct condensation.

3. The 5'-chloropyridylamide of β -(5-chloropyridyl-2)-aminocrotonic acid (VIII, a) was obtained in the sameway as the preceding compound in a 60% yield by the condensation of 5-chloro-2-acetoacetyl aminopyridine with 5-chloro-2-aminopyridine. M.p. 244-246°.

III. The Synthesis of 1,2-(3'-Halogen-divinylene)-6-methylpyrimidones-4

1. 1,2-(3'-Iododivinylene)-6-methylpyrimidone-4 (IX, c). a) A mixture of 10 g (0.045 mole) of 5-iodo-2-aminopyridine and 6 g (0.045 mole) of acetoacetic ester was heated in a Claisen flask on an oil bath at 185-195° for 25-30 minutes. The reaction product obtained was a dark brown, tarry mass. It was treated with 40 ml of cold methanol. The crystalline product which separated out was insoluble in methanol. It was filtered off and washed with methanol. There was obtained 3.8 g of a substance with m.p. 187-190°. After 2 crystallizations from methanol with carbon, this had a constant m.p. of 192-193° (light yellow needle-shaped crystals). Weight 2.5 g. For analysis, the substance was dried in a vacuum at 100° for 5 hours.

0.1098 g substance: 9.7 ml N₂ (25°, 746 mm).

0.1220 g substance: 10.25 ml N₂ (19°, 761.5 mm).

0.1882 g substance: 0.1542 g AgI.

Found %: N 9.62, 9.77; I 44.29.

C₉H₇ON₂I. Computed %: N 9.76; I 44.36.

From the first methanol mother liquid there could be obtained, by means of fractional treatment with petroleum ether and subsequent crystallization, 1.8 g of the original 5-iodo-2-aminopyridine, plus a small amount of a substance with m.p. 82-84°. This was identical with the previously obtained β -(5-iodopyridyl-2)-aminocrotonic ester.

The yield of 1,2-(3'-iododivinylene)-6-methylpyrimidone-4 amounted to 25%, computed on the basis of the 5-iodo-2-aminopyridine which had reacted.

b) A solution of 3.5 g of 5-iodo-2-acetoacetyl aminopyridine (VI, c) with m.p. 173-174° in 8 ml of concentrated sulfuric acid was heated on a boiling water bath for 15 minutes. After cooling, the yellow transparent solution was poured into 50 ml of cold water, filtered with charcoal, and while still warm was made alkaline with a solution of ammonia, until it had an alkaline reaction to litmus. The precipitate which separated out was filtered off, washed with water, and then with cold methanol. There was obtained 2.6 g of a substance (78.8%) with m.p. 190-192°. After one crystallization from methanol, the substance had m.p. 192-193°, and did not give a depression of the melting point with 1,2-(3'-iododivinylene)-6-methylpyrimidone-4 obtained by direct condensation.

From the methanol mother liquid obtained by washing the impure reaction product there was obtained 0.6 g of a substance with m.p. 127-129°. This was 5-iodo-2-aminopyridine.

2. 1,2-(3'-Bromodivinylene)-6-methylpyrimidone-4 (IX, b). a) A mixture of 10 g of 5-bromo-2-aminopyridine (0.057 mole) and 7.5 g of acetoacetic ester (0.057 mole) was heated on an oil bath in a Claisen flask at 190-195° for 40 minutes. The dark, tarry reaction product was treated with 50 ml of cold methanol and the insoluble residue was filtered off. Weight 5.5 g. The product obtained was treated with a large amount (250-300 ml) of hot methanol and the insoluble residue was filtered off (1.3 g). This substance, after crystallization from a large volume of chloroform, had m.p. 238-240°, and was the 5'-bromopyridylamide of β -(5-bromopyridyl-2)-aminocrotonic acid.

The methanol solution was concentrated to a volume of 70 ml and the yellow product which crystallized out was filtered off. Weight 3.8 g, m.p. 161-165°. After crystallization from benzene and methanol, there was obtained 2.7 g of a substance in the form of light yellow needles with a constant m.p. of 169-170°. Yield 20%. For analysis, the substance was dried in a vacuum at 80° for 4 hours.

0.1270 g substance: 12.5 ml N₂ (19°, 760.5 mm).

0.1610 g substance: 0.1252 g AgBr.

Found %: N 11.44; Br 33.05.

C₉H₇ON₂Br. Computed %: N 11.72; Br 33.42.

The remaining methanol mother liquid was not investigated further.

b) A solution of 4.3 g of 5-bromo-2-acetoacetylaminopyridine (VI, b) in 12 ml of concentrated sulfuric acid was heated on the boiling water bath for 15 minutes. The solution was cooled, and poured into 60 ml of cold water. It was then filtered with carbon and treated with ammonia until there was an alkaline reaction to litmus. The precipitate which formed was filtered off, washed with a small amount of warm methanol, and dried. There was obtained 3.1 g of substance with m.p. 161-164°. After crystallization from methanol there was obtained a substance (2.6 g) which had m.p. 168-170° and did not give a depression of the melting point with 1,2-(3'-bromodivinylene)-6-methylpyrimidone-4 obtained by direct condensation. Yield 66%.

After the methanol had been driven off from the methanol mother liquids and wash liquids, and the residue recrystallized from benzene, 0.6 g of material with m.p. 135-137° was obtained. This was 5-bromo-2-aminopyridine.

3. 1,2-(3'-Chlorodivinylene)-6-methylpyrimidone-4 (IX, a). a) This was obtained in the same way as the preceding compound by heating a mixture of equimolecular amounts of 5-chloro-2-aminopyridine and acetoacetic ester at 190-195° for 30 minutes, followed by treatment with cold methanol and crystallization from methanol. The substance, which had a constant m.p. of 165-166°, was obtained in

22% yield. It corresponded in analysis to the cyclic condensation product.

0.1276 g substance: 6.1 ml N_2 (18°, 748 mm).

0.1314 g substance: 0.0952 g AgCl.

Found %: N 14.45; Cl 17.92.

$C_9H_7ON_2Cl$. Computed %: N 14.39; Cl 18.22.

The intermediate reaction products were not investigated.

b) In the same way as before, a solution of 2.3 g of 5-chloro-2-acetoacetylaminopyridine (VI, a) in 6 ml of concentrated sulfuric acid was heated on a boiling water bath for 15 minutes. After dilution with water and neutralization with ammonia, the precipitate which formed was filtered off and washed with a small amount of warm methanol. After crystallization from methanol, the substance had m.p. 165-166°, and did not give a depression of the melting point with the product obtained by direct condensation. Weight 2.2 g. Yield 63.4%.

From the methanol mother liquids, 0.3 g of 5-chloro-2-aminopyridine was obtained.

SUMMARY

1. From the condensation product of 5-halogen-2-aminopyridines with acetoacetic ester, under definite conditions, three substances were obtained: 5-halogen-2-acetoacetylaminopyridine (VI), the 5-halogendipyridylamide of β -(5-halogenpyridyl-2)-aminocrotonic acid (VIII), and the β -(5-halogendipyridyl-2)-aminocrotonic ester (VII).

2. Under more severe conditions, the condensation resulted in the formation of a fourth reaction product, which from its analysis corresponded to the cyclic product with the composition $C_9H_7ON_2Hal$ (IX); this fact indicates the possibility of the cyclic condensation of the halogen substituted α -aminopyridines.

LITERATURE CITED

- [1] N.F.Kucherova, V.F.Kucherov, K.A.Kocheshkov, J.Gen.Chem. 16, 1706 (1946).
- [2] S.N.Khitrik, J.Gen.Chem. 9, 1109 (1939).
- [3] M.S.Kondakova, Ya.L.Goldfarb, J.Gen.Chem. 10, 1065 (1940).
- [4] W.Sexton, J.Chem.Soc., 1942, 303; G. Jacini, Chem. Zentr., 1942, 11, 2261.

Received December 21, 1948.

AN INVESTIGATION OF THE MECHANISM OF THE CLAISEN REARRANGEMENT

A. S. Fomenko and E. A. Sadovnikova

The L. V. Pisarzhevsky Institute of Physical Chemistry
of the Academy of Sciences of the Ukrainian SSR

Rearrangement to the Ortho Position

In order to explain the rearrangement of allyl ethers to give allyl phenols. (the Claisen rearrangement), different mechanisms have been proposed, all of them variants of two main points of view. In accordance with the first, advanced by Claisen himself [1], the rearrangement takes place intramolecularly, by way of intermediate ring-formation which results from the addition of the γ -carbon of the allyl group to a nuclear carbon, and this is followed by the breaking of the initial C-O bond. Following this, enolization leads to the formation of the final product, and allylphenol. Hurd and Pollack [2] and others gave detailed schemes for this mechanism for the electronic point of view.

A ring-formation mechanism gives a good explanation of the majority of the facts connected with the ortho-rearrangement: the fact that the reaction is of the first order, its apparently intramolecular course, and the presence of an inverse allyl group which to a great extent accompanies the transformation. On the other hand, this mechanism, from steric considerations, is not well adapted to the para rearrangement, and is incapable, without many artificial adjustments, of explaining the absence, in this case, of the inverse allyl group.

These difficulties are eliminated by the second point of view [3,4], in accordance with which the rearrangement takes place by an intermolecular method which is preceded by the dissociation of the ether into ions or radicals, whose subsequent recombination leads to new products. The dissociation mechanism, however, also comes into conflict with a number of facts: the lack of catalytic action of acids, bases, and basic solvents [4], and the high yields in a medium where we might expect the intermediate radicals to be bound to extraneous molecules. The question is complicated by the fact that the same kinetics have been found for both rearrangements, with almost the same numerical values of the energy and entropy of activation [4]. This fairly satisfactorily indicates that in both cases, the slow stage of the reaction is the same.

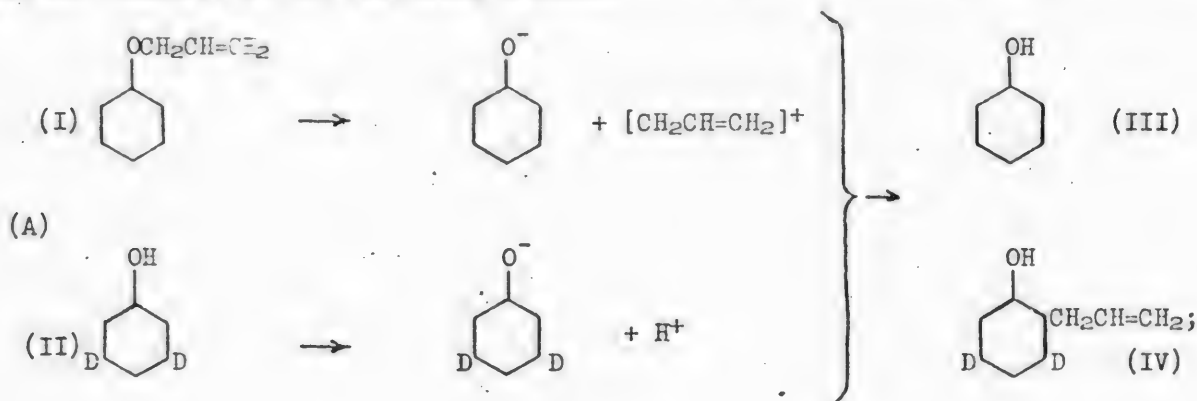
Thus, the question of the mechanism of the Claisen rearrangement remains completely unclear. Each of the two variants is in accord with a number of facts, and in conflict with a number of others, so that these facts lead to a cyclic mechanism for the ortho rearrangement and a dissociation mechanism for the para rearrangement. On the other hand, the similarity in the course of the reaction and the kinetic data forces us to assume that both variants have the same mechanism.

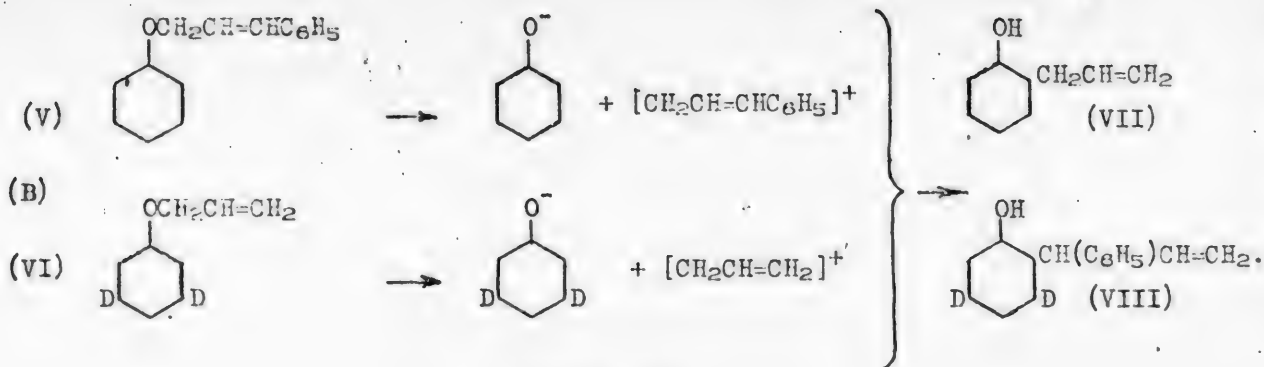
As the first step in explaining the mechanism of the Claisen rearrangement,

it was important to decide whether it took place intramolecularly or intermolecularly, independently of the further details of one or another variant. Hurd and Schmerling [2] attempted to do this by investigating the rearrangement of a mixture of cinnamyl-phenyl and allyl-8-naphthyl ethers. They did not observe any o-allylphenol in the products of the rearrangement, and this should have been formed if the reaction took place intermolecularly. This work, which is sometimes considered a basic contribution to the support of the intramolecular mechanism, is, however, insufficient evidence because of the great difference between the two nuclei, the phenyl and the naphthyl. As a result of this, the interchange of ions or radicals might have failed to take place in this particular case. This objection may be countered by the use of an isotope method, which would permit us to mark one of the two phenyl nuclei, which are identical with respect to their chemical properties, with deuterium, and thus to differentiate between the two ethers and the products of their rearrangement without regard to their chemical properties. This method had been previously used in our laboratory [5] in order to clarify the mechanisms of the hydrogen rearrangement.

The isotope method has also been used by Kistiakowsky and Tichenor [6] to investigate the Claisen rearrangement. However, this work led only to trivial results: to the demonstration that after rearrangement, the ortho or the para hydrogen respectively of the phenyl nucleus had changed places with the allyl group, and from the experimental point of view, it was far from irreproachable, as from 25 to 42% of the deuterium disappeared in side reactions which were not explained by the authors.

We used the isotope method in order to elucidate the question of the mechanism of the ortho rearrangement of allylphenyl ethers. For this purpose we investigated the ortho rearrangement of allylphenyl ether $C_6H_5OCH_2CH=CH_2$ (I) in the presence of 3,5-dideuterophenol, $C_6H_3D_2OH$ (II), and of cinnamylphenyl ether, $C_6H_5OCH_2CH=CHC_6H_5$ (V) in the presence of allyl-3,5-dideuterophenyl ether, $C_6H_3D_2OCH_2CH=CH_2$ (VI). In these experiments, we started from the following considerations. If the process of ortho rearrangement takes place intramolecularly, then the products of the rearrangement of allylphenyl ether (I) in the presence of compounds (II) should not contain 2-allyl-3,5-dideuterophenol (IV), and the products of the rearrangement of cinnamylphenyl ether (V) in the presence of compound (VI) should not contain o-(α -phenylallyl)-3,5-dideuterophenol (VIII). In case there was a bimolecular mechanism, compounds (IV) and (VIII) would be formed as the result of an exchange of allyl groups (for allylphenyl ether) and of cinnamyl groups (for cinnamylphenyl ether) between light and heavy phenol residues, as, for example, in the following schemes:





EXPERIMENTAL

Allylphenyl ether (I) was synthesized by us from allyl chloride and phenol by a method described by Houben-Weyl [7]. After purification, the product had a b.p. 110° at 45 mm.

The 3,5-dideuterophenol (II) was obtained by a method developed in our laboratory [5], and the deuterium content in each of its meta positions amounted to 24,700 γ ($1\gamma = 1 \cdot 10^{-6}$ density unit).

The ortho rearrangement of allylphenyl ether was carried out by boiling it with a mixture of 3,5-dideuterophenol without a solvent, in an atmosphere of nitrogen, for 6 hours. Because of the accumulation of o-allylphenol, the boiling point rose from 193 to 219° . As control experiments showed, the presence of the phenol did not influence the course of the reaction.

After the rearrangement, the o-allylphenol was extracted, together with the 3,5-dideuterophenol, with a 20% solution of sodium hydroxide, which was then acidified with hydrochloric acid until there was a weak acid reaction. The mixture of phenols which was thus obtained was extracted with benzene and fractionated three times in vacuum. An o-allylphenol fraction was isolated which boiled within the limits $98-100^\circ$ at 6 mm. The o-allylphenol thus obtained, in 65% yield, was burned over copper oxide, and the density of the water thus formed was measured by the flotation method. The results of the measurements are presented in Table 1 (Experiments 1, 2, and 3).

TABLE 1

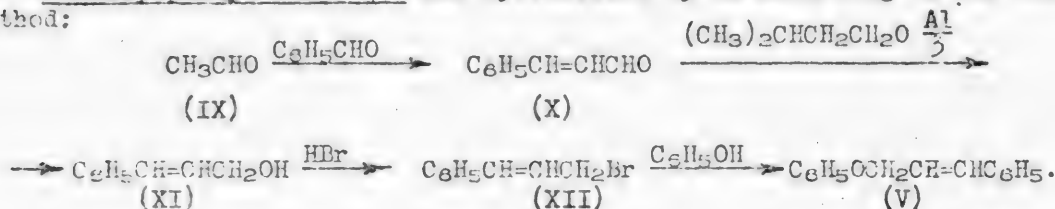
The ortho rearrangement of allyl phenyl ether in a mixture with 3,5-dideuterophenol (without a solvent)

Experiment No.	Amount of allyl phenyl ether, g	Amount of 3,5-dideutero-phenol, g	Density of water from combustion of o-allylphenol (in γ units)	Density computed in γ units
1	12.19	0.71	5	377
2	12.15	0.70	7	372
3	12.30	1.33	2	657
4	12.17	0.71	20	378
5	12.12	0.70	11	370

In another series of experiments, the separation of the o-allylphenol and the 3,5-dideuterophenol was carried out by precipitating the o-allylphenol with mercuric chloride. For this purpose, the mixture of phenols indicated was extracted from the reaction mixture with a 20% solution of sodium hydroxide, the alkaline solution was acidified, and the phenols were extracted with benzene. The benzene was driven off from the mixture, and the latter dissolved in water,

to which mercuric chloride was then added in an amount sufficient for the extraction of all the o-allylphenol. The mixture was then shaken for 4 hours. The o-allylphenol precipitated from solution in the form of crystals of 2-chloromercuro-methyl-1,2-dihydrobenzofuran. During this, the 3,5-dideuterophenol remained in solution. The crystalline precipitate was filtered, washed with water, dried, and subjected to combustion. The measurements of the density of the water obtained are presented in Table 1 (experiments 5 and 6).

Cinnamylphenyl ether (V) was synthesized by us according to the following method:



Cinnamic aldehyde (X). After we had tried out several methods for the synthesis of cinnamic aldehyde [8] described in the literature, the most satisfactory appeared to be the method of Isagulyants, which we utilized in our work (the condensation of acetaldehyde with benzaldehyde). The product was fractionated in vacuum; b.p. 137-138° at 28 mm; yield 56%.

Cinnamyl alcohol (XI) was obtained by the method of Isagulyants [8], by the reduction of the cinnamic aldehyde (X) by means of aluminum isoamylate. The product, which was purified by saponification with an aqueous alcoholic solution of alkali, was extracted with benzene, and purified by distillation in vacuum. The fraction collected had b.p. 138° at 8 mm, m.p. 29-30°. Yield 53%.

Cinnamyl bromide (XII) was obtained by the method of Claisen and Tietze [1] by shaking cinnamyl alcohol with aqueous hydrobromic acid (48%) at room temperature. The yield was quantitative.

The cinnamyl ether (V) was obtained, also by the method of Claisen and Tietze [1], from cinnamyl bromide and phenol. The product, after being recrystallized from petroleum ether in the presence of silica gel, had m.p. 67°; yield 90%.

Allyl-3,5-dideuterophenyl ether (VI), in the presence of which the rearrangement of the cinnamylphenyl ether took place, was obtained from allyl bromide and 3,5-dideuterophenol by the usual method of preparation of allylphenyl ethers [7]. After fractionation in vacuum, a product was obtained which boiled within the limits 104-106° at 40 mm. The deuterium content in each of its meta positions corresponded to 12,850 γ, and was found from the density of the water resulting from the combustion over copper oxide of a mixture of 0.468 g of deuterium-containing and 8.569 g on non-deuterium-containing allylphenyl ether. The density of the water obtained, determined by the flotation method, was 133 γ. Computing the dilution of the deuterium with hydrogen (as a result of the mixing of the two ethers) as being equal to $\frac{8.569 + 0.468}{0.468} = 19.3$, and taking account of the presence of only two atoms of deuterium in the 10 hydrogen atoms of allylphenyl ether, the content of deuterium in the allyl-3,5-dideuterophenyl ether amounted to $133 \times 19.3 \times 10/2 = 12,850 \gamma$.

The rearrangement of a mixture of cinnamylphenyl and allyl-3,5-dideuterophenyl ethers was carried out in diethylaniline. The amounts of substances used are given in Table 2. 50 ml of solvent was used. The mixture was boiled for 4 hours in an atmosphere of carbon dioxide at 223-226°. After the mixture had been cooled, an equal volume of gasoline was added to it. The diethylaniline was re-

removed from the mixture by repeated shaking with dilute hydrochloric acid. After the complete removal of the diethylaniline, there appeared in the mixture the products of rearrangement which were little soluble in the gasoline layer. As Claisen and Tietze [1] showed, the products of the rearrangement of cinnamyl-phenyl ether is o-(α -phenylallyl)-phenol, which was extracted together with the o-allylphenol by shaking the mixture with 3% aqueous sodium hydroxide. The alkaline solution of phenols was treated with activated carbon in order to decolorize it, filtered, and acidified with a dilute solution of sulfuric acid until there was a faintly acid reaction. The mixture of phenols that separated during this was extracted with ether, and the ether extract was washed with a dilute solution of sodium acetate, dried, the ether driven off, and the residue fractionated in vacuum. As the boiling points of o-(α -phenylallyl)-phenol and o-allyl phenol differed by 70°, they could easily be separated by fractionation. At 10 mm, a fraction was collected which boiled within the limits 176.5-177.5°, and was o-(α -phenylallyl)-phenol. This was subjected to combustion over copper oxide, and the density of the water obtained was determined by the flotation method. The values of the density of the water found by us are presented in Table 2.

TABLE 2

The ortho rearrangement of cinnamylphenyl ether in a mixture with allyl-3,5-dideuterophenyl ether (mixture dissolved in 50 ml of diethylaniline)

Expt. No.	Amount of cinnamyl phenyl ether, g	Amount of allyl-3,5-dideuterophenyl ether, g	Density of water from combustion of o-(α -phenylallyl)-phenol (in γ units)	Density computed (in γ units)
1	10.07	0.98	6	244
2	10.37	1.13	18	270
3	10.80	0.72	22	172
4	10.29	0.56	0	144

In both tables, the computations of the density were carried out by starting from the assumption that during the rearrangement, the deuterium was distributed between the phenols in proportion to the number of moles used.

Consideration of Results

From the results obtained by us, we can draw the conclusion that in each case, the ortho rearrangement took place in an intramolecular manner. The considerations mentioned at the beginning of this communication do not permit us to accept a cyclic mechanism as final, and further conclusions must await an investigation of the para rearrangement, and further data on the inversion of the allyl group.

The results cited above with regard to the kinetic investigations of Tarbell and Kincaid [4] force us to seek a general mechanism for the ortho and para rearrangements.

The previously presented mechanism (A) represents a possible course of the. The conclusion of Tarbell and Kincaid to the effect that their kinetic data are in favor of a monomolecular mechanism are not irreproachable. If in solution, the velocity constant of the first order is fairly constant, none the less, in the pure ether it increases considerably with time, and in this case, the kinetics rather appear to be of the second order, or in transition toward it. This has been observed both for the ortho and the para rearrangements.

ortho rearrangement of allylphenyl ether by a bimolecular mechanism, with the formation of intermediate ions. The data obtained by us for allylphenyl ether testify to the absence of the intermediate formation of such ions during the rearrangement. However, it is possible to assume the formation of o-allylphenol by a bimolecular mechanism which includes the cleavage of the allylphenyl ether into phenyl and allyl radicals, whose recombination gives o-allylphenol. As the decomposition of 3,5-dideuterophenol into radicals is improbable, then in this specific case no bimolecular mechanism can be ascribed to this cause. In the case of the second example studied by us, of the rearrangement of a mixture of cinnamylphenyl and allyl-3,5-dideuterophenyl ethers, this doubt disappears, and we may with certainty exclude the bimolecular course of the Claisen ortho rearrangement.

We wish to express our appreciation to Prof. A.I. Brodsky, in whose laboratory the work was carried out, for his invaluable advice and unflagging interest, and also to G.P. Miklukhin, for his continual participation in discussion.

SUMMARY

1. The ortho rearrangement of allylphenyl ether into o-allylphenol has been investigated in the presence of 3,5-dideuterophenol. It has been shown that the products of reaction contain no o-allyl-3,5-dideuterophenol.

2. The ortho rearrangement of cinnamylphenyl ether into o-(α -phenylallyl)-phenol has been investigated in the presence of allyl-3,5-dideuterophenyl ether. It has been shown that the products of rearrangement contain no o-(α -phenylallyl)-3,5-dideuterophenol.

3. On the basis of the data obtained, the conclusion has been drawn that the ortho rearrangement of the ethers under investigation takes place by means of an intramolecular mechanism.

LITERATURE CITED

- [1] L. Claisen and E. Tietze, *Ber.*, **58**, 275 (1925).
- [2] C. Hurd and L. Pollack, *J. Org. Chem.*, **3**, 550 (1939).
- [3] C. Hurd and L. Schmerling, *J. Am. Chem. Soc.*, **59**, 107 (1937).
- [4] D. Tarbell and J. Kincaid, *J. Am. Chem. Soc.*, **61**, 3085 (1939); **62**, 728 (1940).
- [5] A.I. Brodsky, G.P. Miklukhin, I.I. Khutenko, I.P. Gragerov, *Proc. Acad. Sci. USSR*, **57**, 463 (1947).
- [6] J. Kistiakowsky and R. Tichenor, *J. Am. Chem. Soc.*, **64**, 2302; (1942).
- [7] I. Houben-Weyl, *Methods of Organic Chemistry*, No. III. State Chem. Tech. Press, 1941.
- [8] B. Backes, *Comptes rend.*, **196**, 1674 (1933); R. Peine, *Ber.*, **17**, 2117 (1884); V.I. Isagulyants, *Synthetic Perfumes* (1946).

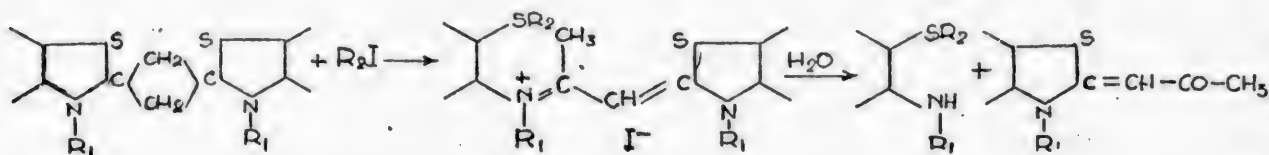
Received February 8, 1949.

THE REACTIONS OF METHYLENE BASES OF THE THIAZOLE SERIES α -HALOGENATED KETONES AND OTHER HALOGEN DERIVATIVES

F. S. Babichev

Department of Organic Chemistry of the Kiev State University

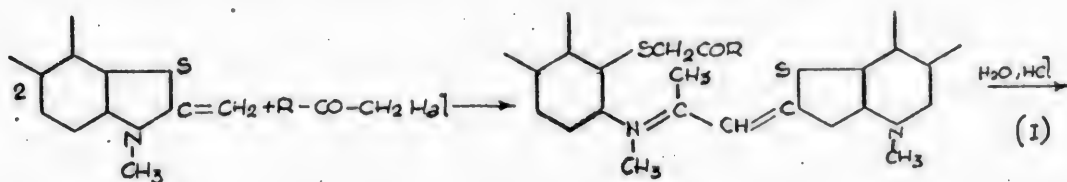
In the work of Kiprianov and Babichev [1], it has been shown that the methylene bases of the thiazole series form with great ease yellow crystalline addition products containing 1 mole of alkyl iodide per 2 moles of the methylene base. In the presence of acids and alkalies, the addition products are easily hydrolyzed. The addition of alkyl iodides to methylene bases of the thiazole series, and the hydrolysis of the products formed take place according to the following equations:

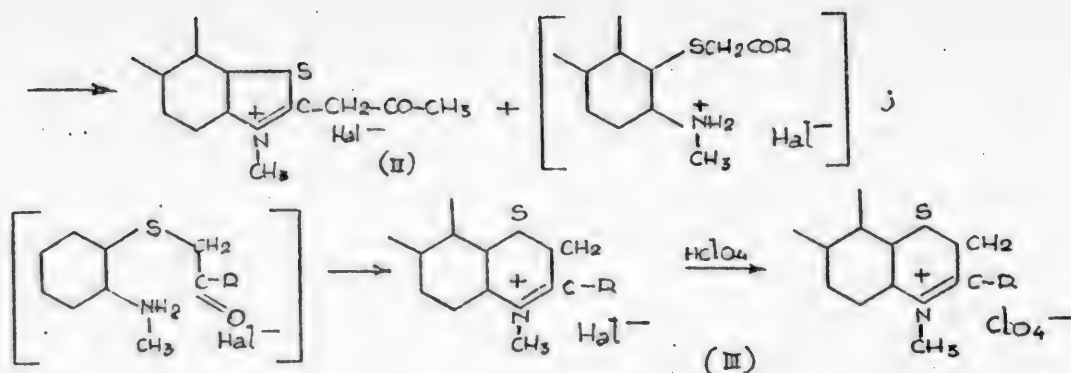


Considering the extraordinary ease with which the methylene bases of the thiazole series react with alkyl iodides, it was to be expected that various other compounds with mobile halogen atoms would behave similarly with alkyl iodides. As our experiments have shown, such compounds include α -halogenated ketones, acid anhydrides, and the esters of α -halogenated acids.

In an investigation of the reaction between α -halogenated ketones and methylene bases, we utilized, for the latter, 3-methyl-2-methylenebenzothiazoline, and 3-methyl-2-methylene- α -naphthothiazoline. As halogenated ketones we used *o*-bromoacetophenone and chloroacetone or iodoacetone. The *o*-bromoacetophenone reacted with identical ease with both methylene bases. The chloroacetone added smoothly only to 3-methyl-2-methylenebenzothiazoline, and even heating of the chloroacetone with the methylene base from 2-methyl- α -naphthothiazole was unsuccessful in giving an addition product, producing only a small amount of the methyl chloride of 2-methyl- α -naphthothiazole. However, if iodoacetone was used instead of chloroacetone, an addition product was easily obtained.

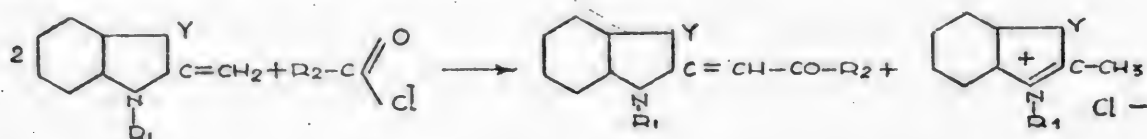
The addition of halogenated ketones, and the hydrolysis of the products formed take place according to the following equations:



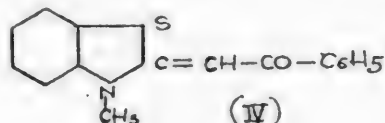


In accordance with this scheme, during hydrolysis, independent of what sort of halogenated ketone was used for the reaction, the hydrogen halide salt of 3-methylacetylmethylenebenzo- or α -naphthothiazoline is formed. The second product of hydrolysis is the quaternary salt of benzothiazine-1,4, obtained somewhat earlier by A.I.Kiprianov and Z.N.Pazenko [2], by another method. The quaternary salt of α -naphtho-1,4-thiazine has not been described in the literature.

The action of acid halides and acid anhydrides on methylene bases was investigated for the first time with indolenine [3] derivatives. It was shown that the products of reaction were acylated methylene bases. The reaction between methylene bases and acid halides acquired practical significance when the acylated methylene bases found application in the synthesis of symmetrical and asymmetrical cyanine dyes. For the production of acylated methylene bases, both the quaternary salts and the methylene bases of nitrogenous heterocycles could be utilized. In accordance with the patent data of the "Kodak" firm [4], acylated methylene bases of the benzothiazole, α -naphthothiazole, and benzseleneazole series are obtained by treating the quaternary salts of these heterocycles with acid chlorides in pyridine. The preparation of acylated methylene bases from the methylene bases and acid chlorides has been described in one of the I.G.patents [5]. According to the patent, the process takes place in such a manner that half of the amount of methylene bases used is converted into acylated methylene base, and half is separated in the form of the quaternary salt.

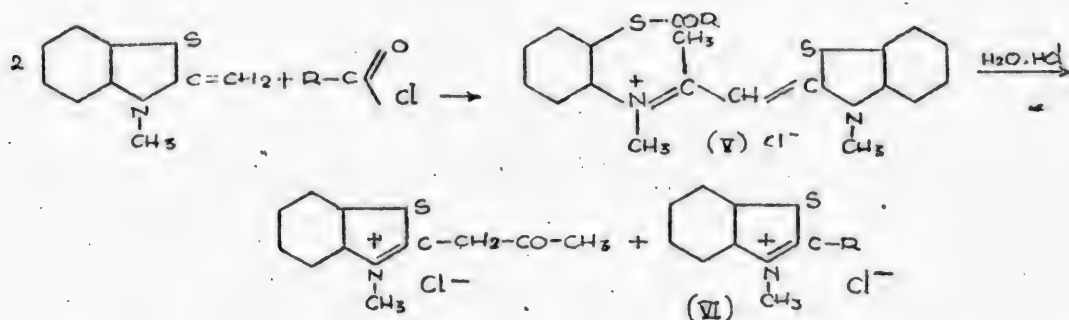


According to the data of this patent, the reaction of 3-methyl-2-methylenebenzothiazoline with benzoyl chloride gives, in accord with the general rule, 3-methyl-2-benzoylmethylenebenzothiazoline (IV).

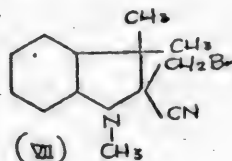


It appeared to us more probable that with acid halides 3-methyl-2-methylenebenzothiazoline would react in the form of a dimer, precisely as it reacts with alkyl iodides and α -halogenated ketones. Experiments which were carried out under the same conditions as indicated in the I.G. patent confirmed our assumption. The action of benzoyl chloride on 3-methyl-2-methylenebenzothiazoline did not give even traces of 3-methyl-2-benzoylmethylenebenzothiazoline. The substance formed in this reaction was an addition product of 1 mole of benzoyl chloride and 2 moles

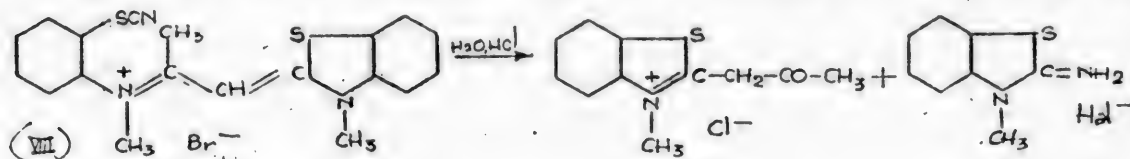
of the methylene base. Acetyl chloride reacts similarly. Thus, the addition of acid chlorides to 3-methyl-2-methylenebenzothiazoline and the hydrolysis of the products obtained proceeds in reality according to the following equations:



Cyanogen bromide is a unique acid halide. In 1939, Mumm and his coworkers [a] showed, by the example of 1,3,3-trimethyl-2-methyleneindoline that cyanogen bromide could be added to the methylene base. The addition product has the structure (VII):



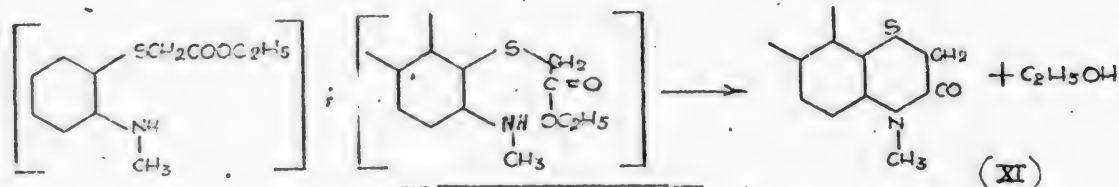
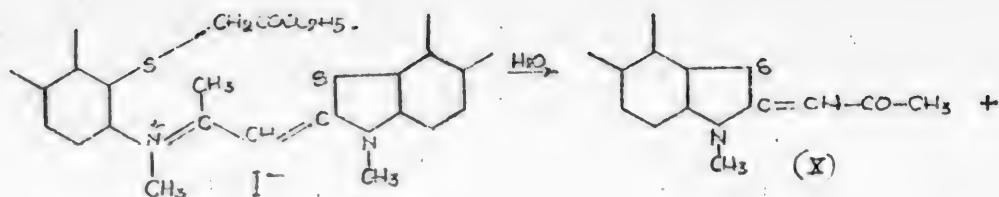
The behavior of 3-methyl-2-methylenebenzothiazoline towards cyanogen bromide was of some interest. As we expected, this methylene base reacted with cyanogen bromide as a dimer. The structure of the addition product (VIII) is confirmed by its hydrolysis, which takes place according to the following equation:



Upon hydrolysis, there is formed, in addition to 3-methyl-2-acetylmethylenebenzothiazoline, 3-methylbenzothiazolonimine.

We were able to show that esters of α -halogenated acids could also react with methylene bases of the thiazole series. There were obtained yellow, crystalline addition products of the ethyl ester of iodoacetic acid to 3-methyl-2-methylenebenzothiazoline and 3-methyl-2-methylene- α -naphthothiazoline. Both these substances were easily hydrolyzed in water or in an aqueous alcoholic medium in the presence of hydrochloric acid.

Upon hydrolysis, 3-methyl-2-acetylmethylenebenzo- or α -naphthothiazoline (X) was formed, plus 4-methyl-1,4-benzo- or α -naphthothiazinone-3 (XI), in accordance with the following equations: (p. 1973). The 4-methyl-1,4-benzothiazinone-3 was identical with the preparation obtained by the reaction of N-methylo-aminothiophenol with chloroacetic acid:



We have seen that methylene bases which contain the thiazole nucleus, upon reacting with alkyl iodides and various other halogen derivatives, give substances which must be regarded as addition products of 1 mole of halogen derivatives to 2 moles of the methylene base. We have assumed that in all these reactions the methylene bases react in the form of dimers. In support of this assumption, there is the observation of Mumm and his coworkers [8], who have shown that 3-methyl-2-methylenebenzothiazoline is completely dimerized in benzene.

It was of interest to determine the molecular weights of the other methylene bases of the thiazole series, and we have done this [1]. The data thus obtained are in accord with our assumption. The methylene bases which react as dimers are actually dimerized, although not completely. We must assume the presence of an equilibrium between the dimers and the monomers.

The present work was carried out under the guidance of Prof. A.I. Kiprianov, to whom the author expresses his deep appreciation.

EXPERIMENTAL

The reaction of 3-methyl-2-methylenebenzothiazoline with monochloroacetone.
6 g of the methylene base, and 3.5 g of monochloroacetone (1 mole) were heated to the boiling point in 40 ml of acetone for 10 minutes. After cooling, the crystalline product was filtered off and washed three times with acetone. The yield was 7.3 g, or 95% of theory, m.p. 162-164° (with decomposition). After recrystallization from 40 ml of alcohol, 6.3 g of material was obtained in the form of faintly yellowish, almost colorless crystals, which melted with decomposition at 166-167°.

Found %: Cl 8.16.

$C_{21}H_{23}ON_2S_2Cl$. Computed %: Cl 8.47.

8 g of the substance with m.p. 166-167° was heated on the water bath for several minutes with 6 ml of concentrated hydrochloric acid and 20 ml of water. Upon cooling, there crystallized from the yellow-brown solution which had formed the hydrochloride of 3-methyl-2-acetylmethylenebenzothiazoline, while in the mother liquid there remained the methyl chloride of 3-methylbenzothiazine-1,4. The action of alkali upon the hydrochloride gave 3-methyl-2-acetylmethylenebenzothiazoline. The yield was 3.7 g, or 95% of theory. The m.p. was 158-160°. After recrystallization from alcohol, the m.p. was 160-161°.

Upon the addition to the mother liquor of 6 ml of 33% perchloric acid, there precipitated the methyl perchlorate of 3-methylbenzothiazoline-1,4 in a yield of 4.55 g, or 86% of theory. After recrystallization from methanol, the perchlorate was in the form of large needles with a straw-yellow color, melting with decomposition at 151-153°. A mixed test for the melting point of this preparation and the 3,4-dimethylbenzothiazine perchlorate prepared by the method of A.I. Kiprianov and Z.N.Pazenko gave no depression.

The reaction of 3-methyl-2-methylenebenzothiazoline with ω -bromoacetophenone.
To a mixture of 4 g of the methylene base and 30 ml of benzene there was added a solution of 2.5 g of ω -bromoacetophenone in 10 ml of benzene. The reaction took place completely in the cold. After several minutes, the contents of the beaker were converted into a porridge of very fine, almost colorless crystals. The yield was 6.5 g, or 100% of theory. Upon heating to 150-155°, the substance turned green, and at 160-163° it melted with decomposition. It was insoluble in water, dissolved slightly in alcohol in the cold, and dissolved well upon heating, but did not crystallize out on cooling.

Found %: N 5.24.

$C_{26}H_{25}ON_2S_2Br$. Computed %: N 5.33.

The action of potassium iodide on a solution of the bromide (m.p. 160-163°) in alcohol gave the iodide as yellow crystals, with m.p. 164-165° (with decomposition).

Found %: N 4.73.

$C_{26}H_{25}ON_2S_2I$. Computed %: N 4.89.

For the purpose of hydrolysis, 4 g of the bromide was heated with 2 ml of concentrated hydrochloric acid and 7 ml of water. In the same way as before, 1.3 g of 3-methyl-2-acetylmethylenebenzothiazoline was obtained, or 86% of theory, plus 2.25 g, or 87% of theory, of 3-phenyl-4-methylbenzothiazoline perchlorate. The latter crystallized from methanol in the form of beautiful lemon-yellow crystals, which melted with decomposition at 192-194°. Our preparation was identical with the 3-phenyl-4-methylbenzothiazine perchlorate prepared by A.I.Kiprianov and Z.N.Pazenko.

The reaction of 3-methyl-2-methylene- α -naphthothiazoline with iodoacetone.
To a suspension of 3 g of the methylene base in 30 ml of benzene there was added all at once a solution of 1.35 g (0.5 mol.) of freshly distilled monoiodoacetone, which did not contain free iodine, in 5 ml of benzene. The mixture was stirred at ordinary temperature for five minutes, and then heated for several minutes on a water bath at 40°. The reaction product precipitated in the form of clear yellow, very fine, but easily filtrable crystals. The yield, after numerous washings with warm benzene, was 4 g, or 92% of theory, the m.p. 158-160° (with decomposition). It began to darken at 140°. The preparation was not soluble in water, benzene, or ether, and dissolved well in the cold in chloroform and dichloroethane. Upon the addition of alcohol it acquired a greasy consistency and dissolved upon heating, but it precipitated from the cooled alcoholic solution in the form of an oil. Upon the addition of methanol or acetone it was also converted into an oil. It was impossible to recrystallize the compound.

Found %: I 20.38.

$C_{29}H_{27}ON_2S_2I$. Computed %: I 20.80.

1 g of the substance with 158-160° was heated on a water bath at 40-50° with 2 ml of concentrated hydrochloric acid and 5 ml of alcohol until there was complete solution, and then for 5 minutes more. Upon cooling, there slowly crystallized from the orange-brown solution which had formed the salt of 3-methyl-2-acetylmethylene- α -naphthothiazoline. The yield of 3-methyl-2-acetylmethylene- α -naphthothiazoline, after recrystallization from alcohol, was 0.26 g, or 63%

of theory. The m.p. was 199-200°. This preparation was identical with the 3-methyl-2-acetylmethylene- α -naphthothiazoline obtained by us by the hydrolysis of the products of alkylation of 3-methyl-2-methylene- α -naphthothiazoline [1].

The addition to the brown mother liquid of perchloric acid precipitated 3,4-dimethyl- α -naphtho-1,4-thiazine perchlorate. After the addition of the first drops of perchloric acid, a dark, viscous mass precipitated, which was separated out. Upon the further addition of perchloric acid, the almost pure perchlorate precipitated out in the form of a yellow crystalline precipitate. The yield was 0.13 g, or 25% of theory; the m.p. 156-158° (with decomposition). The compound could be recrystallized from alcohol.

Found %: N 4.42.

$C_{14}H_{14}O_4NSCl$. Computed %: N 4.27.

The reaction of 3-methyl-2-methylene- α -naphthothiazoline with ω -bromoacetophenone. To a suspension of 3 g of the methylene base in 20 ml of benzene there was added a solution of 1.45 g (0.5 mol.) of ω -bromoacetophenone in 5 ml of benzene. After several minutes, a yellow, very finely crystalline mass formed, which upon heating on a water bath was converted into a viscous oil. The product, which hardened upon cooling, was ground with benzene and washed on a filter several times with hot acetone. It was then in the form of a yellow, finely crystalline powder, m.p. 150-153° (with decomposition). The yield was 4.45 g (theoretical yield 4.43 g). The preparation was insoluble in benzene and ether, and dissolved well in alcohol upon heating. Upon evaporating the alcoholic solution, it precipitated in the form of an oil.

Found %: N 4.26.

$C_{34}H_{28}ON_2S_2Br$. Computed %: N 4.48.

2 g of the preparation which had been obtained, 2 ml of concentrated hydrochloric acid, and 10 ml of alcohol were heated to boiling. An orange-brown solution formed. From this there quickly crystallized out upon cooling the hydrochloride of 3-methyl-2-acetylmethylene- α -naphthothiazoline. The yield of acetylmethylene base after recrystallization from alcohol was 0.55 g, or 67% of theory. The m.p. was 200-201°. Upon the addition of 1.5 ml of 33% perchloric acid to the orange-brown filtrate there precipitated 3-phenyl-4-methyl- α -naphtho-1,4-thiazine perchlorate. The yield was 1.05 g, or 84% of theory. After recrystallization from methanol or glacial acetic acid the compound was in the form of yellow-brown needles, m.p. 204-205° (with decomposition).

Found %: N 3.55.

$C_{18}H_{16}O_4NSCl$. Computed %: N 3.59.

The reaction of 3-methyl-2-methylbenzothiazoline with acetyl chloride. A solution of 1.2 g of acetyl chloride in 10 ml of benzene was added to a mixture of 4.8 g of the methylene base in 20 ml of benzene. The reaction took place in the cold. A light yellow, difficultly filtrable substance was formed. The yield was 5.85 g, or 98% of theory. The melting point without recrystallization was 108-111° (with decomposition). The preparation was insoluble in benzene and ether, very soluble in alcohol, chloroform, and dichloroethane. It crystallized badly, and therefore the iodide was obtained by the action of potassium iodide.

To a solution of 2.9 g of the chloride in 15 ml of alcohol there was added a solution of 1.3 g of potassium iodide in 3 ml of water. The crystals of potassium chloride which precipitated out in the cold were filtered off, and the iodide crystallized out from the filtrate. The yield was 2.55 g. The iodide, recrystallized twice from alcohol, was in the form of light yellow needles, which began to turn red at 134-138°, and melted with decomposition at 152-154°.

Found %: N 5.67; I 25.79.

$C_{20}H_{21}ON_2S_2I$. Computed %: N 5.64; I 25.58.

3 g of the chloride which had been obtained, 3 ml of concentrated hydrochloric acid, and 5 ml of water were heated to boiling. Upon cooling, the hydrochloride of 3-methyl-2-acetylmethylbenzothiazoline crystallized out, and there remained in solution the methyl chloride of 2-methylbenzothiazole. From the hydrochloride, 3-methyl-2-acetylmethylenebenzothiazoline was obtained in the usual way, in a yield 73% of theory, with m.p. 159-160°. To the concentrated solution of the methyl chloride of 2-methylbenzothiazole there was added 2.3 g of 33% perchloric acid. The yield of perchlorate after recrystallization from alcohol was 1.35 g, or 71% of theory; the m.p. was 125°. A mixed test for the melting point of this preparation and the perchlorate obtained from the methyl methosulfate of 2-methylbenzothiazole gave no depression.

The reaction of 3-methyl-2-methylenebenzothiazoline with benzoyl chloride.
To a suspension of 4.1 g of the methylene base in 20 ml of acetone there was added all at once a solution of 1.8 g (0.5 mol.) of benzoyl chloride in 3 ml of acetone. A yellow-orange oil was formed. This rapidly crystallized with the evolution of heat. The crystals were ground with acetone and washed on the filter with acetone. The yield was 5.7 g, or 97% of theory.

The action of potassium iodide on the solution of chloride in alcohol gave the iodide, which after recrystallization from alcohol was in the form of clear yellow, fairly large crystals. M.p. 179-181° (with decomposition).

Found %: N 4.82; I 23.15.

$C_{25}H_{23}ON_2S_2I$. Computed %: N 5.01; I 22.73.

3 g of the product obtained by the addition of benzoyl chloride to the methylene base, 3 ml of concentrated hydrochloric acid, and 15 ml of water were heated for several minutes at 90°. An orange-yellow solution was formed. From this there crystallized out on cooling the hydrochloride of 3-methyl-2-acetylmethylenebenzothiazoline. From the salt, the acetylated methylene base was obtained. The yield was 1.1 g, or 82% of theory; the m.p. was 159-161°.

The methyl chloride of 2-phenylbenzothiazole, which remained in solution, was converted into the methyl iodide. After recrystallization from water, 1.95 g of the methyl iodide of 2-phenylbenzothiazole, or 85% of theory, was obtained. This was in the form of golden yellow platelets, m.p. 201-203° (with decomposition). A mixed test for the melting point of this preparation and the methyl iodide of 2-phenylbenzothiazole obtained by the method of A.I. Kiprianov and I.N. Pazenko [7] from N-methyl-o-aminophenyl mercaptan and benzoyl chloride gave no depression.

The methyl iodide of 2-phenylbenzothiazole dissolved slowly in alkali. The action of dimethyl sulfate on the alkaline solution gave a colorless crystalline substance with m.p. 108°. A mixed test of this substance and the benzoyl derivative of o-methylmercapto-N-methylaniline gave no depression of the melting point.

Found %: N 5.51.

$C_{14}H_{15}ONS$. Computed %: N 5.70.

The reaction of 3-methyl-2-methylenebenzothiazoline with cyanogen bromide.
To a solution of 10 g of the methylene base in 150 ml of benzene, cooled to +6°, there was added, drop by drop, with constant stirring, a solution of 3.3 g (0.5 mol.) of cyanogen bromide in 40 ml of benzene. The finely crystalline product of reaction that formed was washed with benzene, and then with acetone. The weight of the precipitate was 10 g. After recrystallization from alcohol, there was obtained 7 g, or 53% of theory, of rose-colored crystals which melted with decomposition at 101-104°.

The iodide was also subjected to hydrolysis, but simpler and more complete separation of the products of hydrolysis was obtained in the case of the chloride.

The substance, after being recrystallized twice more from alcohol, was in the form of light yellow crystals; m.p. 105-106° (with decomposition).

Found %: N 9.46.

$C_{19}H_{18}N_3S_2Br$. Computed %: N 9.72.

4 g of the preparation which had been recrystallized from alcohol, 3 ml of concentrated hydrochloric acid, and 15 ml of water were heated for several minutes to the boiling point. After the solution had been cooled, the hydrochloride of 3-methyl-2-acetylmethylenebenzothiazoline was filtered off. From the salt there was obtained 1.2 g (63% of theory) of the acetylated methylene base with m.p. 159-160°. To the mother liquid there was added a solution of caustic soda, until the reaction was alkaline. The 3-methylbenzothiazolonimine that separated out was filtered off and recrystallized from water. Part of the product did not dissolve in water, and remained in the form of a brown oil, which was also insoluble in hydrochloric acid. After recrystallization, the yield was 0.6 g, or 39% of theory; the m.p. was 118-120°. After further recrystallization from water, colorless platelets were obtained with m.p. 123°. The compound dissolved very little in cold water, but was very soluble in ether, benzene, and chloroform.

Found %: N 16.78.

$C_8H_8N_2S$. Computed %: N 17.07.

The hydrochloride was obtained as colorless needles, m.p. 275°, and the picrate as yellow needles with m.p. 230°. 3-Methylbenzothiazolonimine as well as the derivatives indicated has been described in the literature [8].

The reaction of 3-methyl-2-methylenebenzothiazoline with the ethyl ester of iodoacetic acid. From 3.5 g of the methylene base and 2.3 g (0.5 mol.) of the ethyl ester of iodoacetic acid in acetone there was obtained 4.5 g, or 79% of theory, of a light yellow, crystalline addition product. After recrystallization from acetone, the m.p. was 143-145° (with decomposition).

Found %: I 23.46.

$C_{22}H_{25}O_2N_2S_2I$. Computed %: I 23.49.

5.5 g of the substance with m.p. 143-145°, 2.5 ml of concentrated hydrochloric acid, and 5 ml of water were heated for several minutes on a water bath. During the heating, a mixture of the hydriodide of 3-methyl-2-acetylmethylene benzothiazoline and a second hydrolysis product, 4-methyl-3-oxodihydro-(benzo-1,4-thiazine) was formed. The hydriodide was filtered off and washed on the filter with ether, in which it was not soluble. The 4-methyl-3-oxodihydro-(benzo-1,4-thiazine) dissolved in ether very well. The yield of the hydriodide of the acetylated methylene base was 3.3 g, or 97% of theory.

The ether solution of the second product of hydrolysis was dried with calcium chloride and the ether was then driven off. In the residue there remained an oil, which quickly crystallized. The yield of 4-methyl-3-oxodihydro-(benzo-1,4-thiazine) was 1.6 g, or 89% of theory; m.p. 53-54°. After recrystallization from petroleum ether it was in the form of shining, colorless platelets, insoluble in alkali and dilute hydrochloric acid, soluble in concentrated acid. M.p. 55°.

Found %: N 8.05, 8.22.

C_8H_9ONS . Computed %: N 7.82.

A mixed test for the melting point of our preparation and the 4-methyl-3-oxodihydro-(benzo-1,4-thiazine) obtained from N-methyl-o-aminophenyl mercaptan gave no depression.

The reaction of 3-methyl-2-methylene- α -naphthothiazoline with the ethyl ester of iodoacetic acid. To a mixture of 4.1 g of the methylene base and 20 ml of

acetone there was added 2.1 g (0.5 mol.) of the ethyl ester of iodoacetic acid. The reaction began after gentle heating and then took place with a considerable evolution of heat. After 30 minutes, the reaction product was filtered with suction and washed with acetone. The yield was 5.2 g, or 85% of theory. M.p. 175-178° (with decomposition).

Found %: I 19.41.

$C_{13}H_{11}O_2N_2S_2I$. Computed %: I 19.82.

3.8 g of the preparation obtained was heated to boiling for several minutes with 1.5 ml of hydrochloric acid and 5 ml of alcohol. After cooling, the colorless crystals were filtered. The weight of the crystals was 3.4 g. They were treated with 20 ml of benzene, the hydriodide of 3-methyl-2-methylene- α -naphthothiazoline remaining in the precipitate, while the second product of hydrolysis dissolved in the benzene. From the salt there was obtained 1.1 g of 3-methyl-2-acetylmethylene- α -naphthothiazoline with m.p. 199-201°.

After the benzene had been driven off, 4-methyl-3-oxodihydro-(α -naphtho-1,4-thiazine) was obtained. After recrystallization from alcohol, the yield was 0.95 g, or 70% of theory. The m.p. was 134°. The preparation was soluble neither in concentrated hydrochloric acid nor in alkali.

Found %: N 6.45, 6.28.

$C_{13}H_{11}ONS$. Computed %: N 6.11.

SUMMARY

The reactions between methylene bases of the thiazole series and α -halogenated ketones, acid halides, and the ethyl ester of iodoacetic acid have been investigated. It has been shown that in these reactions yellow crystalline addition products are formed from 1 mole of the halogen derivative and 2 moles of the methylene base. These addition products are easily hydrolyzed in the presence of acids and alkalies.

Addition products have been obtained from chloroacetone (and iodoacetone) and α -bromoacetophenone to 3-methyl-2-methylenebenzothiazoline and to 3-methyl-2-methylene- α -naphthothiazoline. Upon the hydrolysis of these products, 3-methyl-2-acetylmethylenebenzothiazoline or 3-methyl-2-acetylmethylene- α -naphthothiazoline were formed, plus the quaternary salts of the 1,4-benzothiazine or the α -naphtho-1,4-thiazine.

Products have been obtained by the addition of acetyl chloride, benzoyl chloride, and cyanogen bromide to 3-methyl-2-methylenebenzothiazoline.

The hydrolysis of these products leads to the formation of 3-methyl-2-acetylmethylenebenzothiazoline and the quaternary salts of 2-methyl- and 2-phenylbenzothiazole, respectively. In the case of the substance obtained from the methylene base and cyanogen bromide, the second product of hydrolysis is 3-methylbenzothiazolonimine.

There have been obtained products of the addition of the ethyl ester of iodoacetic acid to 3-methyl-2-methylenebenzothiazoline and 3-methyl-2-methylene- α -naphthothiazoline. Upon the hydrolysis of these substances, 3-methyl-2-acetylmethylenebenzothiazoline or 3-methyl-2-acetylmethylene- α -naphthothiazoline plus 4-methyl-3-oxodihydro-(benzo-1,4-thiazine) or 4-methyl-3-oxodihydro-(α -naphtho-1,4-thiazine) were formed.

LITERATURE CITED

- [1] A. J. Kiprianov and F. S. Babichev, J. Gen. Chem. 20, 145 (1950).

9. [2] A.I.Kiprianov and Z.N.Pazenko. Proc. Acad. Sci. Ukr. USSR, 1949, No. 3,
- [3] Ferratini, Chem. Zentr., 1894, II, 787.
- [4] Kodak, British patent 466,269; Chem. Zentr., 1937, II, 4393; Kodak, German patent 670,505, Chem.Zentr., 1939, I, 2876.
- [5] I.G., French patent 829,442; Chem. Zentr., 1939, I, 808.
- [6] O. Mumm, H. Hinz, J. Diederichsen, Ber., 72, 2109 (1939).
- [7] A.I.Kiprianov and Z.N.Pazenko, Scientific Collection, Proc. Inst. Org. Chem. (in Ukrainian), 13, (75) (1947).
- [8] E.Besthorn, Ber., 43, 1522 (1910); K. Dost, ber., 39, 1014 (1906).

Received January 24, 1949.

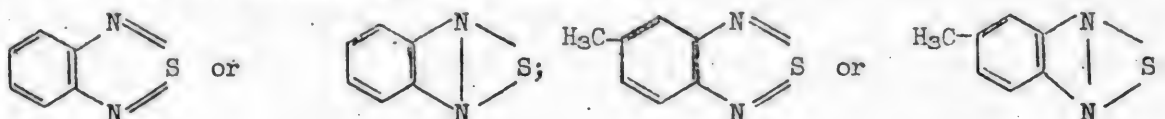
THE SYNTHESIS OF PIAZOTHIOLE (3,4-BENZ-1,2,5-THIODIAZOLE)

AND OF ITS DERIVATIVES

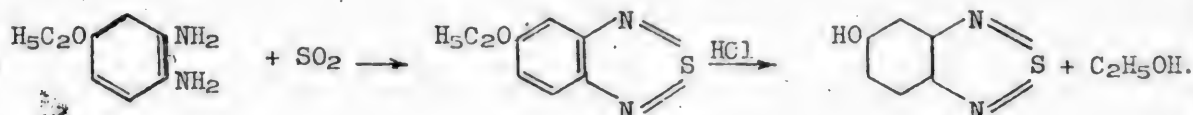
A. M. Khaletsky and V. G. Pesin

The Leningrad Scientific-Research Chemico-Pharmaceutical Institute

Piazothiole was obtained for the first time by Hinsberg by the action of sulfur dioxide on o-phenylenediamine [1]. In a patent which referred to this reaction it was indicated that upon heating aromatic o-diamines like o-phenylenediamine or o-toluylenediamine, for example, to from 100 to 250°, with sulfurous acid or sodium bisulfite, sulfur-containing substances would be formed of the composition $C_6H_4N_2S$ or $C_7H_6N_2S$, possessing the structures:

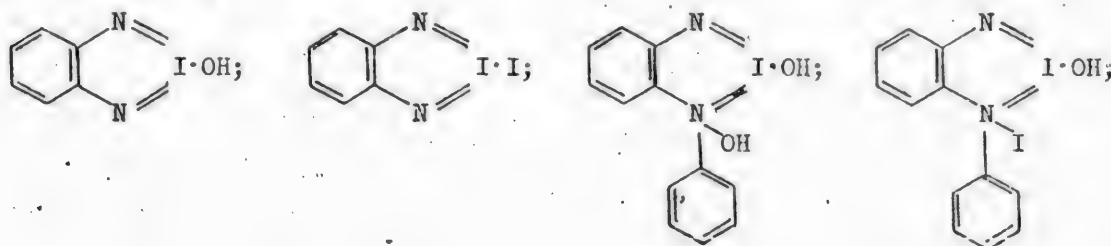


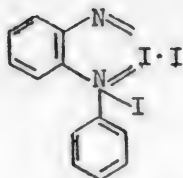
By the action of sulfurous acid on 4-ethoxy-1,2-phenylenediamine, Autenrieth and Hinsberg obtained β -ethoxypiazothiole [3]; when the latter was heated with concentrated hydrochloric acid, β -hydroxypiazothiole was obtained:



A characteristic property of piazothiole and its derivatives is its ability to form with mineral acids easily hydrolyzed salts. Methylpiazothiole forms a chloroplatinate with the composition $(C_7H_6N_2S)_2 \cdot H_2PtCl_6$. With bromine or iodine, piazothiole reacts easily to form bromo and iodo substituted derivatives; methylpiazothiole forms a perbromide. It has not been possible to carry out the synthesis of piazothiole by the action of phosphorus pentasulfide on benzofurazan. It has been found that β -ethoxypiazothiole is more stable than β -ethoxyquinexaline.

To the class of o-diazoles under consideration we may refer in addition the heterocycles obtained by Hugel [4]. These contained iodine, and were called derivatives of piaziodonium:

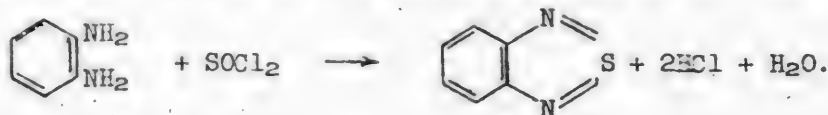




The question of the structure of plazothiole cannot be considered to be decisively settled. In Hinsberg's opinion [5], the stability of the plazothiole ring is determined by the bonds of the sulfur not only with the nitrogen, but with the carbon as well. The trinuclear system which thus arises also influences the stability of the plazothiole nucleus.

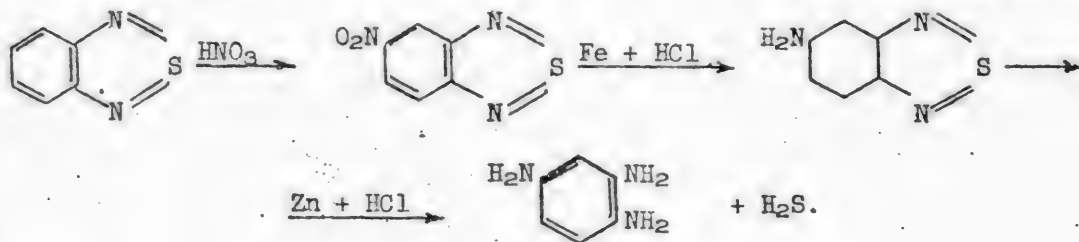
We must note that with similar heterocycles containing oxygen or selenium, stability of the system is observed only when the molecule contains one or more benzene nuclei. The views of Hinsberg to the effect that plazothiole has a trinuclear system seemed to us to have little probability. The author falls into error when, from the fact of the absence of stable bonds in compounds in which the sulfur or selenium is bound only to the nitrogen, he draws the conclusion about the impossibility of existence of stable compounds of such series; as an example, the analogs of plazothiole, as well as its derivatives, can serve. We may assume that the plazothiole nucleus is more stable than, for example, that of quinoxaline, because of the presence of the five-membered heterocycle, in which there are no hydrogens capable of being substituted by radicals.

It appeared to us that the synthesis of plazothiole under the experimental conditions of Hinsberg took place with extremely low yields (5 to 10%); on the other hand, in the reaction of *o*-phenylenediamine with thionyl chloride, plazothiole can be obtained in 84 to 88% yields according to the reaction:



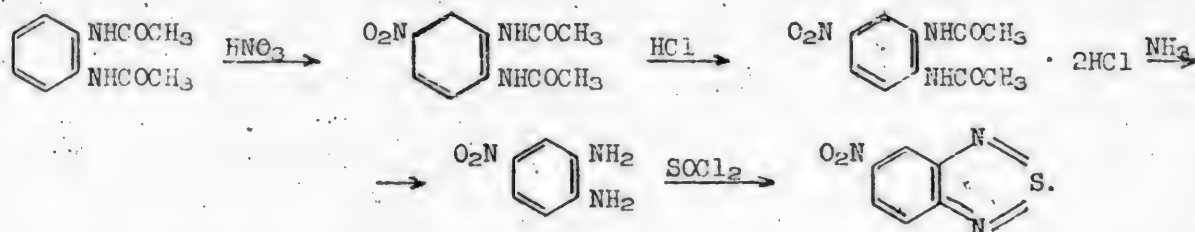
When plazothiole is nitrated, β -nitropiazothiole is easily formed, with m.p. 103° , and when the latter is reduced with hydrogen, it gives β -aminopiazothiole, with m.p. $66-68^\circ$. Upon the continued action of hydrogen on nitropiazothiole, triaminobenzene and hydrogen sulfide are formed.

The nitration and reduction may be indicated in the following manner:

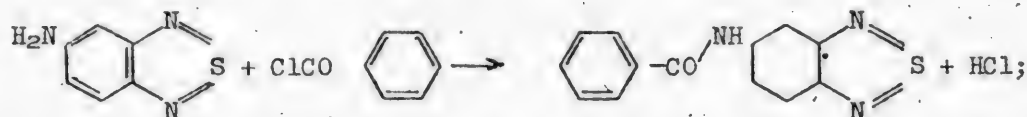


We showed the structure of nitropiazothiole by synthesis. Upon nitrating N^1, N^2 -diacetyl-*o*-phenylenediamine with nitric acid in the presence of sulfuric acid, there was formed 4-nitro- N^1, N^2 -diacetyl-*o*-phenylenediamine with m.p. $226-227^\circ$, and when the latter was saponified with 10% hydrochloric acid, the hydrochloride of nitrophenylenediamine was formed. When the hydrochloride of nitrophenylenediamine was treated with a solution of ammonia, 4-nitro-1,2-phenylenediamine was obtained with m.p. 198° . And when the latter was condensed with thionyl chloride, β -nitropiazothiole was obtained, apparently identical with that which was obtained by the nitration of plazothiole.

The entire course of the transformations may be expressed by the following reactions:



The presence of an amino group in aminopiazothiazole permits us to carry out its condensation with benzoyl chloride:



when the condensation product is saponified with a 20% solution of hydrochloric acid, β -aminopiazothiazole is again obtained, along with benzoic acid.

EXPERIMENTAL

The preparation of piazothiazole from o-phenylenediamine and sodium bisulfite. To a thick-walled tube with a capacity of 75 ml there was added 1 g of o-phenylenediamine, and 7 ml of an aqueous solution of sodium bisulfite, sp. gr. 1.3 (bisulfite content 32%, sulfur dioxide content 20%), and the mixture was heated in the sealed tube for 6 hours at 190-200°. Upon cooling, the reaction mixture had two layers; the lower was crystalline and of a gray color, while the upper was liquid, and colored red-brown. When the tube was opened, 5 ml of benzene was added. It was then observed that the crystalline mass dissolved with the formation of two layers. The upper was of benzene, with a light-yellow color, and the lower was an aqueous layer, colored cherry red. The contents of the tube were filtered with suction. The filtrate was placed in a separatory funnel, and after the lower, aqueous layer had been removed, the upper, benzene layer was decanted into a crystallizer. As the benzene evaporated off, long, colorless needles separated. They had a sharp odor, and m.p. 42°. The yield was 1.1 g, which amounted to 88% of theory.

The preparation of piazothiazole from o-phenylenediamine and thionyl chloride. In a round-bottomed flask with a 5 liter capacity, containing 50 g of o-phenylenediamine, there were placed 2200 ml of absolutely dry toluene and 150 g of thionyl chloride. The flask was connected with a large reflux condenser, fitted with a calcium chloride tube. Immediately upon the addition of the thionyl chloride, the reaction mixture acquired a yellow color. The contents of the flask were heated on an oil bath for 14 to 15 hours, and then subjected to fractional distillation: The piazothiazole went over at 206-210°, and melted at 43-44°. The fraction which went over up to 206° melted at 44°. The yield was 52.5 g, which amounted to 84% of theory.

The piazothiazole was a weak base, soluble in concentrated mineral acids with the formation of colorless solutions. The salts formed were easily hydrolyzed by dilution with water. The piazothiazole could be extracted from such a solution with benzene. Piazothiazole hydrochloride was insoluble in concentrated hydrochloric acid. With aniline, piazothiazole formed a yellow solution. Piazothiazole was distinguished by its great stability; it distilled without decomposition. It was unchanged upon heating to 250° in the presence of mercuric chloride (HgCl_2).

Neither potassium dichromate nor concentrated sulfuric acid acted upon it. Piazothiole was slowly oxidized by a dilute slightly acid solution of potassium permanganate.

It was impossible to isolate an oxidation product with the composition $C_6H_4ON_2S$. Piazothiole was less stable to reducing agents. Thus, upon heating it with zinc and hydrochloric acid, it decomposed with the evolution of hydrogen sulfide and the formation of o-phenylenediamine. Nitrous acid and acetic anhydride had no action upon it.

0.3126 g substance: 0.6068 g CO_2 ; 0.0864 g H_2O .

0.1832 g substance: 33.85 ml N_2 (20°, 758 mm).

Found %: N 20.97; C 52.48; H 3.07.

$C_6H_4N_2S$. Computed %: N 20.59; C 52.94; H 2.94.

β -Nitropiazothiole. To a round-bottomed flask with 0.5 liter capacity, fitted with a stirrer, there were added 25 g. of piazothiole and 70 ml of concentrated sulfuric acid. The flask was placed in a cooling mixture. At 0°, and with continuous stirring, there was slowly added to the flask from a dropping funnel a nitrating mixture which consisted of 15 ml of nitric acid, sp. gr. 1.4, and 22 ml of concentrated sulfuric acid. When the addition of the nitrating mixture was complete, the cooling mixture was removed, and the temperature of the reaction mixture was raised to 20° and kept at this level for a half hour, then the mixture was poured on 0.5 kg of ice. The light yellow precipitate which formed was filtered with suction, washed with ice water until the reaction was neutral, and dried to constant weight at 75°. The yield was 30 to 31 g (90 to 93% of theory); the m.p. was 103°.

β -nitropiazothiole was in the form of light yellow needles, very soluble in benzene, toluene, chloroform, methyl and ethyl alcohols, and glacial acetic acid, insoluble in ether.

0.2085 g substance: 0.3003 g CO_2 ; 0.0302 g H_2O .

0.1656 g substance: 32.83 ml N_2 (17°, 764 mm).

0.1905 g substance: 0.2453 g $BaSO_4$ (Carius).

Found %: C 39.27; H 1.61; N 23.02; S 18.05.

$C_6H_3O_2N_3S$. Computed %: C 39.78; H 1.66; N 23.20; S 17.68.

0.0050 g substance: 0.1012 g camphor; Δt 11° (Rast)

Found: M 181.8.

$C_6H_3O_2N_3S$. Computed: M 181.

β -Aminopiazothiole. To a round-bottomed flask of 2.5 liter capacity, containing 7 or 8 g of iron filings and 1350 ml of water, and joined to a two-way adapter, one end of which was connected with an air condenser, there was added 15 ml of acetic acid, after preliminary heating of the contents of the flask to 70 or 80°. The mixture was then heated to the boiling point. To the boiling reaction mixture there was added through the adapter 25 g of nitropiazothiole, suspended in 150 g of hot water. The boiling was continued for 0.5 hour. The reaction mixture was cooled to room temperature. It had a brown color. It was carefully made alkaline with soda and filtered with suction from the iron sludge. Upon filtering with suction, immediately after being made alkaline, a cloudy filtrate was obtained. This was extracted with ether in order to remove the aminopiazothiole. The ether extract was dried over calcium chloride and filtered off. Most of the ether was driven off, the rest of the solution, which had a red color, being poured into a crystallizer. Yellow-brown needles separated out. After recrystallization from water, they melted at 68°. The yield was 16.5 g (80% of theory).

The β -aminopiazothiole was in the form of yellow-brown needles, very soluble in ether, alcohol, benzene, toluene, methyl alcohol, and chloroform. The color of

the solutions it formed varied with the concentration from light yellow to brown. It was slightly soluble in cold water, more soluble in hot, and was slightly volatile with steam. With concentrated hydrochloric acid it formed a hydrochloride, which was easily hydrolyzed upon dilution. From the aqueous solution the aminopiazothiole could be extracted with ether.

The aminopiazothiole hydrochloride was not soluble in ether. It dissolved to a slight extent in an excess of concentrated hydrochloric acid. With concentrated alkali, aminopiazothiole formed a solution with a black color. The same sort of solution was formed by the action of dilute alkali; upon standing, the color of the solution changed, and acquired tints from light yellow to dark yellow.

In contrast to piazothiole, aminopiazothiole was less stable to oxidizing and reducing agents. Potassium dichromate and 1 to 2% solutions of potassium permanganate converted it into a black amorphous mass. Upon prolonged heating with zinc and hydrochloric acid, there was formed, in addition to a tarry mass, triaminobenzene and hydrogen sulfide.

0.2127 g substance: 0.3699 g CO₂; 0.0666 g H₂O.

0.2070 g substance: 49.93 ml N₂ (19°, 756 mm).

0.1825 g substance: 0.2847 g BaSO₄ (Carius).

Found %: C 47.43; H 3.48; N 27.44; S 21.43.

C₆H₅N₃S. Computed %: C 47.68; H 3.31; N 27.81; S 21.19.

0.0053 g substance: 0.1000 g camphor; Δ t 14° (Rast).

Found: M 151.4.

C₆H₅N₃S. Computed: M 151.

p-Nitrobenzoylaminopiazothiole. To a round-bottomed flask with 0.750 liter capacity, joined to a reflux condenser, and containing a solution of 6 g of aminopiazothiole in 250 ml of dry toluene, there was added 8.2 g of p-nitrobenzoyl chloride in 50 ml of toluene. Immediately upon the addition of the solution, cloudiness appeared. The reaction mixture was heated to the boiling point for 1.5 hours, and then the toluene was driven off and the hot concentrated solution was poured into the crystallizer. Needles of a light yellow color separated out, with m.p. 207°. The yield was 10 g (83% of theory).

The condensation product was very soluble in boiling toluene, benzene, and chloroform. It was slightly soluble in methyl and ethyl alcohols, and insoluble in water, ether, and toluene. The color of the solutions it formed was lemon-yellow. The action of dilute alkali gave a light-yellow solution, which quickly acquired a more intense color, and became black. Upon heating with dilute alkali, or upon the addition of concentrated alkali, the solution blackened.

Dilute hydrochloric acid did not act upon the condensation product. At a sufficiently high concentration, such as 20%, hydrochloric acid, upon prolonged boiling, saponified it with the formation of the original amine and nitrobenzoic acid. Upon boiling for 3 to 4 hours with 20% hydrochloric acid, partial decomposition took place.

0.2873 g substance: 0.5449 g CO₂; 0.0711 g H₂O.

0.2564 g substance: 41.36 ml N₂ (18.5°, 752 mm).

0.2437 g substance: 0.1961 g BaSO₄ (Carius).

Found %: C 51.73; H 2.75; N 18.31; S 11.05.

C₁₃H₈O₃N₄S. Computed %: C 52.0; H 2.66; N 18.66; S 10.66.

0.0054 g substance: 0.0981 g camphor; Δ t 7.4° (Rast).

Found: M 298.

C₁₃H₈O₃N₄S. Computed: M 300.

The reduction of β-aminopiazothiole. To a flask of 50 ml capacity, containing 2.5 g of zinc filings and 6 ml of 20% hydrochloric acid, and joined to a

two-way adapter and an air condenser, there was added, with heating, 1 g of aminopiazothiole in 6 ml of 20% hydrochloric acid. The mixture was heated for 1.5 hours.

The cooled reaction mixture was filtered with suction, and the filtrate evaporated on the water bath until crystallization began. After the entire mass had crystallized out, 2 to 3 ml of concentrated hydrochloric acid was added, and the same amount of alcohol. The precipitate was filtered off with suction. The grayish crystals placed in a test tube, and a saturated solution of caustic potash was added. To the solution was added a mixture of chloroform and ether. Upon evaporation of the solvent, vitreous needles began to separate out. These were carefully filtered with suction, washed with a mixture of ether and chloroform, and dried on a calcined clay plate. After washing with a mixture of chloroform and ether, the crystals melted at 97-98°, which corresponded to the melting point of 1,2,5-triaminobenzene.

N¹,N²-Diacetyl-o-phenylenediamine. To a flask of 250 ml capacity, containing 10 g of o-phenylenediamine, and joined by means of a two-way adapter to a reflux condenser, there was added 40 g of acetic anhydride. The reaction mixture was heated for 10 minutes. The crystals which formed were filtered with suction and washed with ice water. The washed, dried precipitate was dissolved in boiling water, and the solution was filtered.

Upon cooling, crystals separated out in the form of long, silky, shining needles with m.p. 185°, corresponding to the m.p. of N¹,N²-diacetyl-o-phenylenediamine.

4-Nitro-N¹,N²-diacetyl-o-phenylenediamine. To a flask of 500 ml capacity, containing 10 g of the diacetyl-o-phenylenediamine, there was slowly added, with cooling with ice, 50 g of concentrated sulfuric acid. At 5 to 8°, there was slowly added a solution of 10 ml of a mixture which consisted of 7 ml of sulfuric acid, sp. gr. 1.84, and 3 ml of nitric acid, sp. gr. 1.48. The reaction mixture, which had a yellow-brown color, was allowed to stand for a day at room temperature, and was then poured on ice.

The light yellow mass was filtered with suction and washed with ice water. The dried precipitate was dissolved in boiling alcohol, filtered while hot, and slowly cooled. The colorless needles which formed had m.p. 226-227°, which corresponded to the m.p. of 4-nitro-N¹,N²-diacetyl-o-phenylenediamine. They were subjected to further treatment in order to remove the 4-nitro-1,2-phenylenediamine.

4-Nitro-1,2-phenylenediamine. To a flask of 250 ml capacity, which contained 7 g of 4-nitro-N¹,N²-diacetyl-o-phenylenediamine, there was added 50 ml of 10% hydrochloric acid. The mixture was heated on the water bath for 15 minutes, and then was filtered while hot and cooled. The 4-nitro-o-phenylenediamine hydrochloride which crystallized out was filtered with suction, washed with cold water, dissolved in hot water, and the solution made alkaline with ammonia. This caused the formation of dark red needles, insoluble in water. The crystals were filtered with suction, washed with cold water, and recrystallized from toluene. The dark red shining leaves that were obtained melted at 198°, which corresponded to the m.p. of 4-nitro-1,2-phenylenediamine.

β-Nitropiazothiole. 2 g of the dry 4-nitro-o-phenylenediamine which had been recrystallized from toluene was added to a round-bottomed flask of 100 ml capacity, which was joined to a reflux condenser fitted with a calcium chloride tube. Then 80 ml of dry toluene and 4 g of thionyl chloride were added.

The reaction mixture was heated for 6 to 7 hours, and then most of the toluene was driven off and the residue filtered with suction. When the toluene was driven off from the filtrate, light yellow needles precipitated out. They melted

at 101-103°, and had all the properties of the β -nitropiazothiole previously obtained. A mixed test gave m.p. 101-103°.

Saponification of the condensation product. To a flask of 50 ml capacity, which contained 1 g of p-nitrobenzoyl-aminopiazothiole, there was added 10 ml of 20% hydrochloric acid. The flask was connected with an air condenser, and the mixture was heated for 4 hours. To the reaction mixture, 10 ml of water was added. The hot, yellow solution was filtered, and from the filtrate there at once began to crystallize light yellow crystals of p-nitrobenzoic acid. The crystals were filtered with suction, and the filtrate made alkaline with soda, and from the alkaline solution there were extracted with ether the yellow-brown needles of β -aminopiazothiole, with m.p. 68°. A mixed test gave m.p. 68°.

SUMMARY

1. A method has been developed for the preparation of piazothiole from o-phenylenediamine and thionyl chloride with a yield from 80 to 85%.

2. β -Nitropiazothiole has been synthesized with a yield of 90-93%, β -aminopiazothiole with a yield of 80%, and p-nitrobenzoyl-aminopiazothiole with a yield of 80-85%.

3. The structures of compounds not described in the literature have been determined.

LITERATURE CITED

- [1] O.Hinsberg, Ber., 22, 2895 (1889).
- [2] German patent 43,131; Fridlender, 2, 534.
- [3] W.Autenrieth and O.Hinsberg, Ber., 25, 501 (1882).
- [4] M.Hugel, Comptes rend., 182, 65 (1926).
- [5] O.Hinsberg, Ber., 22, 862 (1889).
- [6] O.Hinsberg, Ann., 260, 48 (1890).

Received December 24, 1948.

INVESTIGATIONS OF THE ALKALOIDS OF THE SPECIES OF SENECIO [1]

VII. ALKALOIDS FROM SENECIO RENARDI

A. Danilova and R. Konovalova

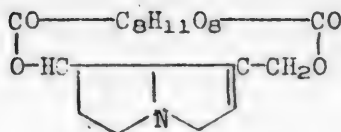
Alkaloid Chemistry Laboratory of the S. Ordzhonikidze All-Union Scientific.
Research Chemico-Pharmaceutical Institute. Moscow.

In the present communication we shall present results obtained by us in an investigation of the plant Senecio Renardi, procured for us by the Central Asian Expedition of the All-Union Scientific Research Chem. Pharm. Institute, under the direction of P.S. Massagetov. Senecio Renardi grows on the slope of the Gissarsky Ridge (Tadzhik Republic), under the Anzobsky Pass. The above ground portion of this plant was collected in July, 1946. It was very poor in alkaloids, whose content amounted to 0.16%. However, as the result of fairly complicated and tedious work, we were able to isolate from this plant four individual alkaloids. The separation of these alkaloids was attained on the basis of their different solubilities both as bases and as salts. The preparation of the mixture of alkaloids was carried out by extracting the plant with dichloroethane and extracting the bases from the alkaline solution with ether and chloroform.

From the mixture of alkaloids, which was difficultly soluble in ether, we obtained a crystalline alkaloid which after repeated crystallization from alcohol and acetone melted at 212-214°. It was difficultly soluble in benzene, alcohol, and acetone. It formed well crystallized salts. The perchlorate, which was soluble with difficulty in water, and did not have a clear melting point, charred at 245°. The picrate of this base melted with decomposition at 185°. The picrolonate had m.p. 176-177°, and crystallized well from alcohol.

We obtained its methyl iodide with m.p. 228-229°. This indicated the tertiary character of the nitrogen. The properties of this alkaloid and of its salts were reminiscent of those of seneciphylline, obtained from S. platyphyllus [1], S. stenocephalus [1], S. vernalis, and S. spartioides [3]. A mixture of the two alkaloids did not give a depression of the melting point. However, the specific rotation of the base obtained by us from Senecio Renardi was $[\alpha]_D -125^\circ$. In order decisively to settle the question of the identity of these two alkaloids, we carried out the hydrolytic cleavage of our alkaloid with alcoholic alkali, and obtained an aminoglycol with m.p. 119-120°. Its hydrochloride had m.p. 164°. A mixed test of the aminoalcohol with retronecine, obtained by one of us by the hydrolysis of seneciphylline [1], did not give a depression of the melting point. The acid which formed in this reaction was identical with seneciphyllinic acid. Thus, there is no doubt that the alkaloid we obtained from Senecio Renardi is seneciphylline [5], whose structure is expressed by the following formula: (p. 1990).

The second alkaloid, also obtained from the ether fraction after numerous crystallizations from acetone and alcohol, was separated in the form of platelets



with m.p. 191-193°. It dissolved readily in ethyl acetate, and with more difficulty in water, acetone, and ether. It formed a crystalline picrate with m.p. 219-220°, and a bitartrate, which dissolved with difficulty in water and had m.p. 197-197.5°. The base obtained from the bitartrate had m.p. 192-193°, and was optically active, with $[\alpha]_D -2.3^\circ$. Its composition was close to the formula $C_{18}H_{25}NO_5$. It contained a methylimide group, thus differing from the majority of the alkaloids obtained from the different species of *Senecio*. Judging from its properties, this alkaloid differed from the previously described bases, and was called by us *renardine*. With methyl iodide, renardine gives a crystalline methiodide, which indicates the tertiary character of the nitrogen. It has a clearly unsaturated character and immediately decolorizes permanganate in sulfuric acid solution.

Renardine, like the other alkaloids, was obtained from different species of *Senecio*, and has the character of an ester. But upon hydrolysis with alcoholic alkali it was possible to obtain only a crystalline acid, while the aminoalcohol completely formed a tar. The acid obtained had the composition $C_{10}H_{16}O_5$, m.p. 148-149°, optical activity $[\alpha]_D -8^\circ$. Upon heating with hydrochloric acid it was converted into a lactone-acid with m.p. 150-152° and $[\alpha]_D +43^\circ$. These properties of the acid coincide completely with the properties of senecionic acid, obtained by the hydrolysis of senecionine [5] and platiphylline. Upon direct comparison of the two acids, it was found that they were identical, and a mixed melting point test gave no depression. Unfortunately, because of the insufficiency of renardine it was not possible for us to repeat experiments on its hydrolysis under different conditions, so that we might obtain the basic fragment and characterize it.

Renardine gives a positive reaction for pyrrole with a pine splinter. Taking account of the presence of the methylimide group in it, we may assume that renardine is a monocyclic base, a derivative of methylpyrrolidine.

The third alkaloid, obtained by us from the chloroform fraction, differs from the bases described above by its slight solubility in ether and acetone. It crystallizes from alcohol or benzene in the form of fine little needles, and melts with decomposition at 218-219°. Its composition approaches the formula $C_{19}H_{27}NO_7$. It is an optically active base with $[\alpha]_D +14.3^\circ$. It is readily soluble in water and chloroform, and soluble with difficulty in benzene. It forms a crystalline picrate, which melts with decomposition at 231-232°. It contains the methylimide group. This alkaloid has a clearly unsaturated character and immediately decolorizes permanganate. Upon heating with a solution of alcoholic alkali, hydrolytic cleavage took place; from this it was impossible to isolate the acid, while the second component, the aminoalcohol, completely underwent tarring. The crystalline acid obtained had the composition $C_{10}H_{16}O_6$, and was optically active, with $[\alpha]_D -27.7^\circ$. It had m.p. 181-182°. These properties of the acid coincide with those of jaconecinic acid, obtained for the first time by the hydrolysis of jacobine [7], and also by the alkaline cleavage of othosenine [2]. The similarity in the properties of our base and of its picrate, and also the complete analogy in the course of the hydrolysis of othosenine led us to consider the possible identity of these substances. In order to confirm our assumption, we isolated othosenine from the roots of *Senecio othonnae*, kindly provided by L.Ya. Areshkina. Upon comparing othosenine with our alkaloid, it was shown that a mixed test, both of the bases themselves, as well as of their picrates, gave no depression of the melting point. The identity of the alkaloid obtained by us with othosenine may thus be considered as demonstrated.

Finally, we were able to obtain a small amount of a fourth alkaloid from the

final mother liquids after the removal of the renardine. This base, on recrystallization from acetone, had m.p. 176-178°, and gave an obvious depression of the melting point with renardine. It was readily soluble in alcohol, ether, and petroleum ether. It formed a crystalline perchlorate, which had no clear melting point. As the composition of this alkaloid was not accurately determined, we temporarily called it "base 4"

In conclusion it was interesting to note that of the four alkaloids isolated from *S.R.*, seneciphylline was a derivative of 1-methylpyrrolizidine, i.e., it had a bicyclic carbazine-condensed system, while two other alkaloids, othonecine and renardine, are to be referred, apparently, to the derivatives of N-methylpyrrolidine. There should be great interest in working on the investigation of the quantitative compositions of the alkaloid mixtures of this plant, depending on the period of vegetation. This may give the opportunity of tracing the transformation of individual alkaloids into each other. The work on the further investigation of the newly discovered alkaloids is being continued.

EXPERIMENTAL

The separation of the alkaloids. 10 kg of the dry, finely divided grass was moistened with 10% NH_4OH and extracted thoroughly with dichloroethane. From the dichloroethane, the alkaloids were extracted with 10% sulfuric acid. The acid solution was cooled, and made alkaline with a 25% solution of ammonia. From the alkaline solution, the alkaloids were extracted first with ether, then with chloroform.

Treatment of the ether extract (separation of seneciphylline, renardine, and "base 4"). Upon driving off the ether until a volume of 250 ml was attained, the alkaloids precipitated, and were filtered with suction and washed with acetone. There was obtained 4 g of base with m.p. 179-182°. From the wash acetone there was obtained 1.02 g of a crystalline substance with m.p. 171-173°. The ethereal mother-liquid was again concentrated, and this resulted in the separation of 2.85 g of a crystalline base with m.p. 170-171°. Finally, after almost all the ether had been driven off, a mixture of bases was obtained, with melting range 157-163°. A small amount of alkaloid remained in the form of tar.

4 g of the alkaloids with m.p. 179-182° was boiled 4 times with 10 ml portions of acetone, the insoluble base being filtered off each time and washed with acetone. After this treatment, there remained 2.12 g of substance with m.p. 210-212°. After this material had been recrystallized from alcohol, the base was obtained with m.p. 212-214°. From it there was formed a picrolonate with m.p. 176-177°, with the overall formula $\text{C}_{18}\text{H}_{23}\text{NO}_5 \cdot \text{C}_{10}\text{H}_8\text{O}_5\text{N}_4$. A mixed test of the base and its picrolonate with seneciphylline and seneciphylline picrolonate, respectively, gave no depression of the melting point.

Upon cooling of the acetone mother liquid after the removal of the seneciphylline, there was obtained 1.1 g of a base with m.p. 196-198°. After recrystallization from acetone and then from alcohol, the latter melted at 192-193° (renardine). Upon concentration of the acetone mother liquid after the removal of the renardine there was obtained 0.8 g of base with m.p. 167-169°; after two recrystallizations from acetone it melted at 176-178°, and gave a definite depression with renardine. It was readily soluble in alcohol, ether, and petroleum ether. As this alkaloid was separated in very small amount, and its composition was not accurately determined, we called it "base 4".

Renardine. This crystallized from acetone or alcohol in the form of thick prisms, with m.p. 192-193°. It was readily soluble in ethyl acetate, less soluble in water, alcohol, acetone, and benzene, difficultly soluble in ether. The sulfuric acid solution of renardine decolorized permanganate in the cold. It was optically active.

0.2948 g substance in 11 ml of chloroform; α_D -0.06° ; $[\alpha]_D$ -2.23° ; $l = 1$.

3.484, 3.009 mg substance; 8.176, 7.060 mg CO_2 ; 2.309, 2.020 mg H_2O .

6.348, 6.806 mg substance: 0.235, 0.250 ml N_2 (19.5° , 746 mm).

Found %: C 64.00, 63.99; H 7.42, 7.51; N 4.17, 4.14

$\text{C}_{18}\text{H}_{25}\text{O}_5\text{N}$. Computed %: C 64.47; H 7.46 N 4.18.

The picrate. The base was dissolved in 10% hydrochloric acid, and to the solution there was added a saturated aqueous solution of picric acid. A precipitate formed. After three recrystallizations from alcohol, the m.p. was $219-220^\circ$.

5.120, 2.612 mg substance: 0.0461, 0.241 ml N_2 (25.5° , 26.5° ,

Found %: N 9.94, 10.13. 734, 733 mm)

$\text{C}_{18}\text{H}_{25}\text{O}_5\text{N} \cdot \text{C}_6\text{H}_3\text{O}_7\text{N}_3$. Computed %: N 9.93.

The bitartrate. This was formed upon mixing hot alcoholic solutions of the base and an equimolecular amount of tartaric acid. The bitartrate immediately separated from the hot solution. After three recrystallizations from alcohol, the m.p. was $197-197.5^\circ$.

0.5030 g substance in 5 ml water; α_D -0.72° ; $[\alpha]_D$ -14.3° ; $l = 0.5$.

3.015, 3.916 mg substance: 6.019, 7.800 mg CO_2 ; 1.817, 2.299 mg H_2O .

7.129, 6.832 mg substance: 0.176, 0.176 ml N_2 (19° , 733.5 mm).

Found %: C 54.45, 54.32; H 6.74, 6.57; N 2.78, 2.90

$\text{C}_{18}\text{H}_{25}\text{O}_5\text{N} \cdot \text{C}_4\text{H}_6\text{O}_8$. Computed %: C 54.43; H 6.39; N 2.93.

The methiodide. 0.1 g of the base in 5 ml of acetone and 2 ml of methyl iodide were heated on a water bath with a reflux condenser for 16 hours. After the acetone had been driven off in the air, the residue was in the form of a viscous material, which was converted into a powder by grinding with ethyl acetate. The methiodide was readily soluble in water, acetone, chloroform, and alcohol, slightly soluble in ether. It was dissolved in absolute alcohol, and absolute ether was added. The precipitate was filtered with suction, washed with ether, dried in a vacuum desiccator. The substance darkened at 190° and charred at $194-196^\circ$.

The hydrolytic cleavage of renardine. A mixture of 1.5 g of the base and 20 ml of 0.5 N alcoholic alkali was heated on the water bath at 60° for one and a half hours. During the heating, the solution became colored, at first dark green, and then dark red. The alcoholic solution was transferred to a dish, and the alcohol evaporated off in the air. The residue was acidified with 10% hydrochloric acid and extracted with ether. The ether solution was dried over calcined sodium sulfate. After the ether had been driven off, there remained 0.85 g of a crystalline acid. The acid aqueous solution, after the extraction of the acid, was made alkaline with 40% NaOH and extracted with chloroform. The chloroform extract was dried with sodium sulfate. After the chloroform had been driven off, 0.5 g of a dark brown tarry substance was obtained.

Purification of the acid. After three recrystallizations of the acid from water, its m.p. was $148-149^\circ$. The acid was readily soluble in alcohol, acetone, and ethyl acetate, difficultly soluble in benzene and chloroform. Upon recrystallization from benzene or chloroform, it separated out in the form of a gel-like mass, and was converted into a powder when filtered with suction. Upon heating with 10% hydrochloric acid, the acid formed a crystalline lactone with m.p. $154-155^\circ$.

The melting point and properties of the acid obtained were extremely close to those of senecionic acid. The melting point of a mixture of the acid from renardine and the acid from platiphylline showed no depression. There was likewise no depression of the melting point when the lactone of this acid was mixed with the lactone of platinecinic acid.

Purification of the aminoalcohol. The aminoalcohol (renarcine) was in the

form of a tarry material which mixed easily with water and organic solvents. We did not succeed in obtaining crystalline salts. An aqueous solution of gold chloride easily reduced the aminoalcohol. The solution of renarcine hydrochloride decolorized an aqueous solution of permanganate in the cold.

Treatment of the chloroform extract (separation of othosenine and renardine). The chloroform extract was concentrated to a volume of 40 to 50 ml and poured into a beaker. After the solvent had been volatilized, there remained a tarry material with a brown color, which upon grinding with acetone was transformed into an amorphous powder. After filtering with suction and washing with acetone, there was obtained 4.6 g of a mixture of alkaloids with m.p. 188-193°. Upon boiling the latter with acetone, part of it went into solution. There remained 3 g of insoluble material with m.p. 209-210°. After two recrystallizations from benzene and a subsequent crystallization from alcohol, a base was obtained with m.p. 218-219° (othosenine). After the othosenine had been separated, a base with m.p. 190-192° was obtained from the acetone mother liquid (renardine).

Othosenine was crystallized from alcohol or benzene in the form of fine small needles, with m.p. 218-219°. It was readily soluble in water, chloroform, and methanol, and difficultly soluble in benzene. A dilute sulfuric acid solution of the alkaloid decolorized permanganate in the cold.

0.3356 g substance in 13 ml CHCl_3 , $\alpha_D + 0.37^\circ$; $[\alpha]_D + 14.3^\circ$; $1 = 1$.

3.315 mg substance: 7.340 mg CO_2 ; 2.068 mg H_2O .

7.994 mg substance: 0.260 ml N_2 (22°, 738 mm).

Found %: C 60.39; H 6.98, N 3.66.

$\text{C}_{19}\text{H}_{27}\text{O}_7\text{N}$. Computed %: C 59.82; H 7.14; N 3.67.

Picrate. The base was dissolved in 5% hydrochloric acid, and to the solution there was added a saturated aqueous solution of picric acid. A crystalline picrate rapidly precipitated. After three recrystallizations from water, the m.p. was 231-232° (with decomposition).

5.684, 4.704 mg substance: 0.457, 0.388 ml N_2 (23.5, 24.5°, 729.5 mm).

Found %: N 8.88, 9.08.

$\text{C}_{19}\text{H}_{27}\text{O}_7\text{N} \cdot \text{C}_6\text{H}_3\text{O}_7\text{N}_3$. Computed %: N 9.17.

Hydrolytic cleavage. 0.9 g of the substance was mixed with 15 ml of 3% alcoholic alkali and heated to 60° for 30 minutes. During the heating the solution acquired a dark red color. The alcohol was evaporated off in the air. The alkaline solution was extracted first with ether, then with chloroform. After the solvent had been driven off, a tarry aminoalcohol was obtained. It was impossible to obtain crystalline salts. The aminoalcohol had an unsaturated nature, and mixed readily with water, alcohol, and acetone. The alkaline solution that was obtained after extracting the aminoalcohol was acidified and the acid was extracted with ether. The ether solution was dried over calcined sulfate. After the ether had been driven off, 0.47 g of a crystalline acid was obtained. After three recrystallizations from water, the m.p. was 180-181°. When the acid was boiled with 10% hydrochloric acid, no lactone was obtained. The acid had a saturated character. It was optically active: $[\alpha]_D + 27.45^\circ$ (0.01 g in 1 ml of alcohol).

The separation of the alkaloids from the roots of *Senecio othonnifolius*. 98 g of the air-dried roots were ground up, moistened with ammonia, and extracted with dichloroethane, from which the alkaloids were extracted with 10% sulfuric acid. The acid solution was filtered, cooled, and made alkaline with ammonia. From the alkaline solution the alkaloids were extracted first with ether, then with chloroform. From the ether fraction, 0.25 g of base was obtained in the form of a brown resin. Upon grinding with a small amount of acetone, 0.05 g of crystals were obtained, m.p. 215-216°. From the chloroform fraction, 0.1 g of a crystalline

alkaloid was obtained with m.p. 214-215°. The base which had been obtained gave no depression of the melting point with the alkaloid othosenine, obtained from Senecio Renardi.

SUMMARY

1. From Senecio Renardi, 4 alkaloids have been isolated; seneciphylline, othosenine, a new alkaloid, renardine, and "Base 4".

2. Renardine has the composition $C_{18}H_{25}NO_5$, and contains a methylimide group, and gives a positive reaction for pyrrole.

3. Renardine is an ester, and upon hydrolysis with alcoholic alkali is cleaved into senecionic acid and a basic fragment which has not yet been obtained in pure form.

4. An investigation of the bases of this plant during all the periods of vegetation would be of undoubted interest, and might cast light on the origin of these alkaloids.

LITERATURE CITED

[1] Previous communication: R. Konovalova and A. Orekhov, J. Gen. Chem. 8, 273, 391, 396 (1938).

[2] E. Zhdanovich and G. Menshikov, J. Gen. Chem. 11, 835 (1941).

[3] R. Manske, Canadian J. Research, 17, 1 (1939).

[4] R. Konovalova and A. Danilova, J. Gen. Chem., 18, 1198, 1202 (1948).

[5] R. Manske, Canadian J. Research, 14, 6-11 (1936).

[6] Barger, J. Chem. Soc., (1936) 743.

[7] Manske, Canadian J. Research, 5, 651-659 (1931).

Received January 21, 1949.

AN INVESTIGATION OF THE ALKALOIDS OF ELAEAGNUS ANGUSTIFOLIA

THE STRUCTURE OF ELEAGNINE

G. P. Menshikov, E. L. Gurevich and G. A. Samsonova

The Phytochemical Laboratory of the S. Ordzhonikidze All-Union Scientific Research Chemico-Pharmaceutical Institute. Moscow.

In 1946, P.S. Massagetov described under the name eleagnine, a new alkaloid which he had isolated from the roots of Elaeagnus angustifolia [1]. Eleagnine was described as a crystalline, optically inactive base with the composition of $C_{12}H_{14}N_2$, with m.p. 180-181°. Later, the work on the investigation of this alkaloid was transferred by P.S. Massagetov to us. Upon a comparison of the eleagnine described by P.S. Massagetov with already known bases, we were struck by the agreement of the melting point of this alkaloid with the melting point of tetrahydroharman (179-180°), which had been synthesized by Tatsui [2]. It was true that the melting point of eleagnine hydrochloride, which according to P.S. Massagetov was 254-255°, differed by 10° from the melting point of tetrahydroharman hydrochloride (265°), but if we take account of the fact that these salts melt with decomposition, and also at a comparatively high temperature, we may assume that this difference depends on the method of determination.

Actually, the eleagnine hydrochloride obtained by us also melted, upon rapid heating, at 264-265°, while upon slow heating its decomposition temperature was somewhat lower. All this made it seem very probable that eleagnine was tetrahydroharman. In order to settle this question, eleagnine was dehydrated by heating with silver acetate (Tafel's method). The alkaloid thus lost 4 atoms of hydrogen, and a weak base, $C_{12}H_{10}N_2$ was obtained, with m.p. 233-234°. This base was directly compared with harman, obtained from harmine by the method of O. Fischer [3]. Their complete identity was thus established. In addition, eleagnine itself was directly compared with tetrahydroharman, which we obtained by reducing harman with sodium in absolute alcohol. Both these substances were also shown to be identical. Thus we may consider it completely demonstrated that eleagnine is the racemic form of tetrahydroharman.

EXPERIMENTAL

The dehydration of eleagnine. 2 g of the alkaloid, 1.5 g of glacial acetic acid, 10 ml of water, and 12 g of silver acetate were heated for 8 hours in tubes at 180°. After the tubes had been opened, their contents were filtered to remove metallic silver, treated with ammonia, and extracted with ether. The ether solution was dried with potash, and the ether driven off. The residue was treated with a small amount of benzene. The entire mass then crystallized. The crystals were filtered with suction and recrystallized several times from benzene. About 1 g of large, slightly colored crystals were obtained, with m.p. 233-234°.

4.574 mg substance: 13.219 mg CO₂; 2.245 mg H₂O.
3.050 mg substance: 8.806 mg CO₂; 1.489 mg H₂O.
Found %: C 78.82; 78.74; H 5.49, 5.44.
C₁₂H₁₀N₂. Computed %: C 79.09; H 5.55.

A mixed test of these crystals with harman, obtained from harmine by the method of O.Fischer [3], gave no depression of the melting point.

The reduction of harman. 1 g of harman, obtained from harmine, was dissolved in 70 ml of absolute alcohol, and to the boiling solution there was added 6 g of metallic sodium. After all the sodium had dissolved, the solution was acidified with a 15% solution of hydrochloric acid. The alcohol was driven off in vacuum, and the residue was made alkaline with a 30% solution of caustic soda, and extracted with ether. The ether solution was dried with potash, and the ether driven off. The crystalline residue was recrystallized from a mixture of alcohol and water. There was obtained 0.35 g of slightly yellow crystals, which melted at 179-180°. A mixed test of these crystals with eleagnine gave the same melting point. The hydrochloride was obtained from the base. The hydrochloride melted at 263-264°, and gave no depression of the decomposition point in a mixed sample with eleagnine hydrochloride.

SUMMARY

It has been shown that the alkaloid eleagnine, isolated by P.S.Massagetov from the roots of Elaeagnus angustifolia, is the racemic form of tetrahydroharman.

LITERATURE CITED

- [1] P.S.Massagetov, J.Gen.Chem. 16, 139 (1946).
- [2] G.Tatsui, Chem. Zentr., 1928, 11, 668; S. Akabori and K. Saito, Ber., 63, 2245 (1930).
- [3] O.Fischer, Chem. Zentr., 1901, 1, 958.

THE JOURNAL OF GENERAL CHEMISTRY
OF THE USSR

Vol. 21 1951

No. 9 (September)

LIBRARY COPY
DO NOT REMOVE
IN ENGLISH TRANSLATION

CONSULTANTS BUREAU
152 WEST 42ND ST. NEW YORK 18, N. Y.

—An agency for the interpretation of international knowledge—

